Analysis of machine tool structure using RSM approach

Submitted to the department of Mechanical Engineering in the partial fulfillment of the requirements for the award of the degree of

Master of Technology
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(Mechanical Engineering)

by

Mr. Ashirbad Swain
(210ME2246)

under the Guidance of
Prof. B. K. Nanda

Department of Mechanical Engineering
National Institute of Technology
Rourkela, Odisha
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Dedicated to my parents

National Institute of Technology
Rourkela

CERTIFICATE

This is to certify that work in this project report entitled, "**Analysis of Machine Tool Structure using RSM approach"** by **Mr. Ashirbad Swain** has been carried out under my supervision and guidance in partial fulfillment of the requirements for the award of **Master of Technology in Production Engineering (*Mechanical Engineering)*** during session 2010-2012 in the Department of Mechanical Engineering, National Institute of Technology, Rourkela.

To the best of my knowledge, this work has not been submitted to any other university/ institute for award of any Degree or Diploma.

Date: (Dr. B. K. NANDA)

Dept. of Mechanical Engineering,
National Institute of Technology,
Rourkela-769008

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Date

(Ashirbad Swain)
210ME2246

ABSTRACT

Unwanted vibration in machine tools like milling, lathe, grinding machine is one of the main problem as it affects the quality of the machined parts, tool life and noise during machining operation. Hence these unwanted vibrations are needed to be suppressed or damped out while machining. Therefore the present work concentrates and aims on study of different controllable parameter that affect the responses like vibration amplitude and roughness of machined part. The part to be machined is kept on sandwich of plates made up of polymer and composite material. The sandwich along with the part to be machined ate fixed on the slotted table of horizontal milling machine. The parameters that can easily be controlled are feed, RPM of cutter, depth of cut, and number of plates that form the secondary bed material..

Polymers like Polyvinyl Chloride (PVC), Polypropylene (PP) plates and composites like Glass Fiber Polyester and Glass Fiber Epoxy (GFE) plates are used in the experiments to form the sandwich (secondary bed material) on which work-piece (MS Plate) was mounted and fed to the milling cutter. Four holes are made on the specimen and the plates to ensure that the sandwich of plate including the work-piece can be bolted to the slotted table.

Common up-milling operation was carried out in controlled manner. Vibration signals were recorded on the screen of phosphorous storage oscilloscope and surface roughness of machined plate was found from the Talysurf. Finite element analysis (FEA) was carried out to know the resonance frequencies at which the structure should not be excited. In the course of the FEA some important facts have come up that lead to set some of the steps of precautions during the experimentation. Response surface methodology (RSM) is used to develop the model equation for each set of plate material.

NOMENCLATURE

m	Mass of the system in Kg
$\ddot{x}$	Acceleration of system in mtr/sec^2
C	Damping coefficient in Ns/m or Kg/ Sec
$\dot{x}$	Velocity in mtr/Sec
k	Spring constant in N/ mtr
x	Displacement in mtr
t	Time in Sec
A, B	Constant
C_c	Critical damping constant in Ns/m or Kg/ Sec
ω_0	Naturan frequency in Rad/ Sec
ζ	Damping Ratio
δ	Logarithmic decrement
A_i	Amplitude for ith oscillation
A_{i+n}	Amplitude for i+nth oscillation
n	Number of Oscillation
f	Damping force in N
c	Friction parameter
$\mathrm{sgn}(\dot{q})$	Signum function
$\dot{q}$	Relative displacement at the joint
y	Response of interest
b_i, b_{ii}	regression coefficient
x_i, x_j	controllable variables
ε	Error observed in the response

[M] Mass matrix

{x} Nodal Displacement vector

$\{\dot{x}\}$ Time derivative of displacement vector or nodal displacement vector

$\{\ddot{x}\}$ Time derivative of nodal velocity vector or nodal acceleration vector

[C] Damping matrix

[K] Stiffness matrix

{f(t)} Force vector as a function of time

X(ω) Nodal displacement as a function of 'ω'

{F(ω)} Force applied at node as a function of 'ω'

[H(ω)] Transfer function matrix

φ Mode shape matrix

ω_i Mode frequency for i^{th} mode

ζ_i Damping ratio for i^{th} mode

$\emptyset_i$ Shape of mode i

Chapter 1: Introduction

1.1 VIBRATION PROBLEM IN MACHINING PROCESS

Machining of any kind is accompanied by vibrations of work-piece and tool. These vibrations occur due to the following reasons [1].

- In-homogeneities in the work piece material
- Variation of chip cross section
- Disturbances in the work piece or tool drives
- Dynamic loads generated by acceleration/deceleration of massive moving components
- Vibration transmitted from the environment
- Self-excited vibration generated by the cutting (machine-tool chatter).

Due to these vibrations the following phenomenon occurs.

- Reduction in tool life
- Improper surface quality
- Undesirable Noise
- Excessive load on machine tool

This phenomenon can be reduced when machine tools have high stiffness [2]. High stiffness in machine tools can be achieved by making them by robust structured materials through passive damping technology.

1.2 VIBRATION OVERVIEW

Dynamic responses of a structure can be determined by three essential parameters

- Mass
- Stiffness
- Damping

Storage of energy is associated with mass and stiffness where as damping results in the dissipation of energy by a vibration of a system. For a linear system, if the forcing frequency is the same as the natural frequency of the system, the response is very large and can easily cause dangerous consequences due to resonance effect. In the frequency domain, the response near the natural frequency is "damping controlled".

1.2.1 DAMPING DEFINITION

Damping is a phenomenon by which mechanical energy is dissipated in dynamic systems. In other words it is also said to be any effect that tends to reduce the amplitude of vibration in an oscillatory system. For a spring mass damper system, the equation of motion is represented by:

$$m\ddot{x} + C\,\dot{x} + kx = 0 \qquad \text{(eq. 1.1)}$$

Where m in (kg) is the mass of the system, k is the spring constant (in N/m), c is the damping coefficient in (Ns/m or Kg/ Sec).

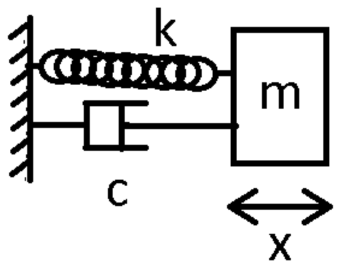


Figure 1 Spring mass damper system

Spring mass damper system

The solution to the above differential equation is

$$x = e^{\frac{c}{2m}t}\left(Ae^{\sqrt{\left(\frac{c}{2m}\right)^2-\frac{k}{m}}} + Be^{-\sqrt{\left(\frac{c}{2m}\right)^2-\frac{k}{m}}}\right) \qquad \text{(eq. 1.2)}$$

For critically damped system

$$\left(\frac{C_c}{2m}\right)^2 - \frac{k}{m} = 0$$

Which gives

$$C_c = 2m\sqrt{\frac{k}{m}} = 2m\omega_0 = 2\sqrt{km} \qquad \text{(eq. 1.3)}$$

Here, ω_0 is the un-damped natural frequency of the system.

So damping ratio is defined as

$$\zeta = \frac{c}{C_c} = \frac{c}{2m\omega_0} = \frac{c}{2\sqrt{km}} \qquad \text{(eq. 1.4)}$$

For a dynamic system, more the value of 'ζ', more the system is said to be damped. There are also other ways to represent the damping of a system i.e. logarithmic decrement and loss factor.

Logarithmic decrement is represented as

$$\delta = \frac{1}{n}\ln\left(\frac{A_i}{A_{i+n}}\right) \qquad \text{(eq. 1.5)}$$

Where 'A_i' is the amplitude of the i^{th} oscillation and 'A_{i+n}' is the amplitude of the oscillation n vibrations after the i^{th} oscillations illustrated in the figure below.

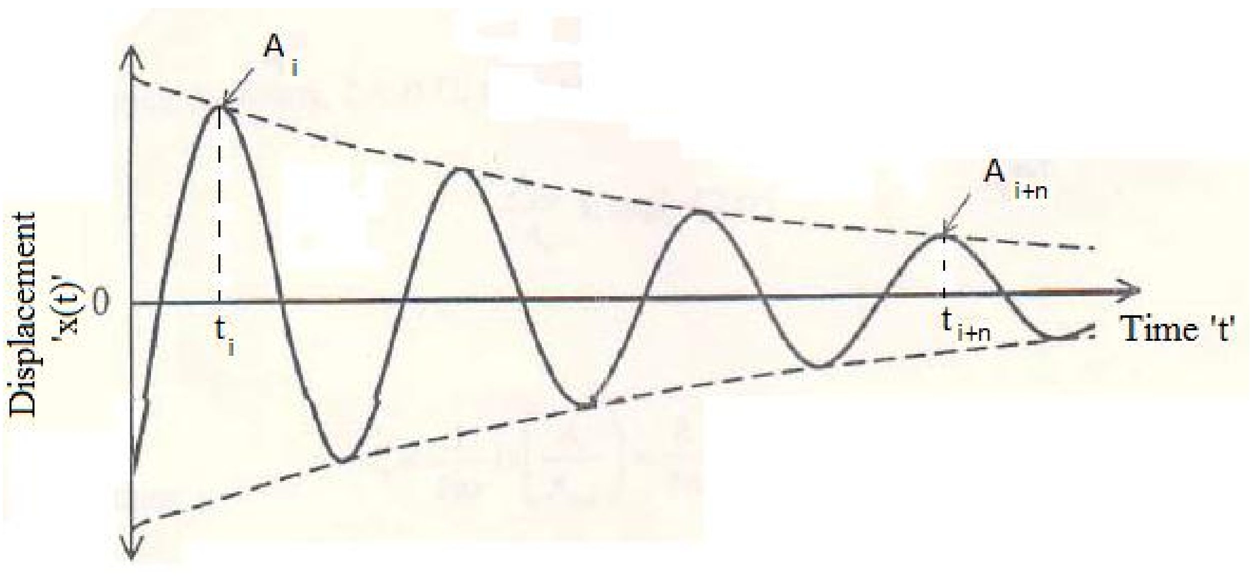


Figure 2 Vibration response of a damped system

Logarithmic decrement and damping ratio are related as

$$\left.\begin{array}{l} \delta = \dfrac{2\pi\zeta}{\sqrt{1-\zeta^2}} \\ \quad\quad or \\ \zeta = \dfrac{1}{\sqrt{1+\left(\dfrac{2\pi}{\delta}\right)^2}} \end{array}\right\} \quad \text{(eq. 1.6)}$$

1.2.2 TYPES OF DAMPING

Three main types of damping are present in any mechanical system and they are: Material (Internal) damping, Structural damping, Fluid damping [3].

A. *Material (Internal) damping:*

Internal damping of materials is related to the energy dissipation associated with micro-structural defects, like grain boundaries and impurities; local temperature gradients resulted from non uniform stresses distribution in vibrating beams; eddy current effects in ferromagnetic materials; dislocation motion in metals; and chain motion in polymers. Several models have been employed to represent energy dissipation caused by internal damping. As variety of models is primarily a result of the vast range of engineering materials; there is no single model that can satisfactorily represent the internal damping characteristics of all materials.

B. *Structural damping:*

Structural damping can be achieved by rubbing friction or contact among different elements in a mechanical system. Model representation of structural damping is very difficult as the dissipation of energy depends on the particular characteristics of the mechanical system which is hard to determine. The Coulomb-friction model can be used to describe energy dissipation caused by rubbing friction. As structural damping which is caused by contact or impacts at joins, energy dissipation is determined by means of the coefficient of restitution of the two components in contact.

For an ideal Coulomb friction, the damping force at a join can be expressed through the following expression

$$f = c.\,\mathrm{sgn}(\dot{q}) \qquad \text{(eq. 1.7)}$$

here ‘f’ is the damping force, ‘c’ is a friction parameter, ‘$\dot{q}$’ is the relative displacement at the joint.

Signum function is defined as

$$\mathrm{sgn}(x) = \begin{cases} 1 \text{ when } (x \geq 0) \\ -1 \text{ when } (x < 0) \end{cases} \qquad \text{(eq. 1.8)}$$

C. *Fluid damping:*

Relative movement of immersed material in a fluid is opposed by the fluid. This is due to drag force upon the material due to fluid. Energy dissipation happens in the due force, hence the motion is said to be damped i.e. the phenomena of fluid damping.

There are two ways damping can occur in a machine tool.

- Active damping
- Passive damping

When damping is achieved by external means for example energy dissipation by the use of controlled actuator are is called active damping whereas Passive damping refers to energy dissipation within the structure by add on damping devices such as isolator, by structural joints and supports, or by structural member's internal damping.

1.2.3 VIBRATION IN MACHINE TOOLS

The Machine, cutting tool, and workpiece together form a structural system which has complicated dynamic characteristics. Vibrations of the structural system, vibrations may be divided into three basic types [1].

A. *Free or Transient vibrations*:

Impulses transferred through machine foundation to the structure, from fast traversals of reciprocating masses like machine tables, or impulses transferred by the initial engagement of cutting tools cause free vibration. The structure is deflected and oscillates naturally until the damping present in the structure causes the motion to diminish to zero.

B. *Forced vibration:*

Forced vibration is said to be occurred by a periodic forces applied to system, like unbalanced rotating masses or the irregular engagement of multi-tooth cutters (in this case milling), or vibration transmitted from nearby machinery through the foundations. The machine tool oscillating at the forcing frequency, and if this frequency matches with to one of the natural frequency or resonant frequency of the structure, the machine will resonate in the corresponding natural mode of vibration.

C. *Self-excited vibrations:*

Dynamic Instability of the cutting process cause Self-excited vibrations. This phenomenon is commonly called machine tool chatter. if large tool-work engagements are given, oscillations build up in the structure. In this case structure oscillates in one of its natural modes of vibration.

1.3 DAMPING IN MACHINE TOOLS

Damping in machine tools basically is derived from two sources one is material damping and other is slip damping. The extent of material damping is very small in comparison to the total damping in machine tools. A typical damping ratio value for material damping in machine tools is in the order of 0.003 which accounts for about 10% of the total damping.

The interfacial slip damping outcomes from the contact surfaces at bolted joints and sliding joints which contribute approximately 90% of the total damping. Welded joints usually provide very small damping which may be neglected when considering damping in joints. Whereas sliding joints contribute most of the damping.

1.4 MAIN OBJECTIVE OF THE RESEARCH WORK

The main objective of the work is to study

- the effect of controllable parameter like feed, RPM, depth of cut and number of layer of secondary bed material on vibration amplitude and surface roughness of machined part.
- To find a model equation that represents a relationship between response and controllable parameter that affects the response by the help of Response Surface Methodology (RSM) using Minitab software.

1.5 WHY TO USE SECONDARY BED MATERIAL (SBM)

The bed (sandwich of composite) intended to act as vibration absorbers. Polymers and composite have been utilized as a bed to the work-piece because of it excellent damping characteristics. Passive damping technology has a wide variety of engineering applications such as follows.

A. Vibration absorber in

- Bridges,
- Engine mounts
- Machine components such as rotating shafts,

B. Component vibration isolation,

C. Novel spring designs which incorporate damping without the use of traditional dashpots or shock absorbers, and structural supports.

Table 1 Loss factor for some of the \ commonly used structure and materials

Systems/Materials	Loss Factor
Welded Metal structure	0.0001 to 0.001
Bolted Metal structure	0.001 to 0.01
Aluminum	0.0001
Brass, Bronze	0.001
Beryllium	0.002
Lead	0.5 to 0.002
Glass	0.002
Steel	0.0001
Iron	0.0006
Tin	0.002
Copper	0.002
Plexiglas TM	0.03
Wood, Fiberboard	0.02

1.6 COMPOSITE AND VISCOELASTIC MATERIALS AS SBM.

A composite material is considered to be one which is a combination of two or more constituent materials on a macroscopically uniform level. The constituents are combined in such a way that they keep their individual physical phases and are neither soluble in each other nor form a new chemical compound.

One constituent is called reinforcing phase where the reinforcing phase is embedded which is called a matrix. Generally, fibers are used as the reinforcing phase and are much stronger than the matrix and the matrix is used to hold the fibers intact. Composited used for the work is Glass fiber epoxy (GFE). In GFE, fiber glass (made from extremely fine fibers of glass) is used as reinforcing agent. Epoxy is a thermosetting polymer formed from reaction of an epoxide (resin) with polyamine (hardener).

Viscoelasticity is a material behaviour characteristic having a mixture of perfectly elastic and perfectly viscous behaviour. All energy is lost as pure damping. For a viscous material, the stress is related to the strain as well as the strain rate of the material. Most of the polymers exhibit Viscoelasticity. In this work the used polymers are Polyvinyl Chloride and Polypropylene.

1.7 RESPONSE SURFACE METHODOLOGY (RSM)

RSM is a collection of statistical and mathematical techniques useful for the development, improvement and optimisation of processes and / product. The first step is to find a suitable approximation for the true functional relationship between response of interest 'y' and a set of controllable variables {x1, x2, ...xn}. Usually when the response function is not known or non-linear, a second-order model is utilized [4].

$$y = b_0 + \sum_{i=1}^{n} b_i x_i + \sum_{i=1}^{n} b_{ii} x_i^2 + \sum\sum_{i<j} b_{ii} x_i x_j + \varepsilon \qquad \text{(eq. 1.8)}$$

Here 'ε' is the noise or error observed in the response. b's are regression coefficient to be estimated and y - ε is expected response. The least square technique is being used to fit a model equation such that residual error (sum of square deviations between the actual and estimated responses) is minimized. Analysis of variance (ANOVA) is used to check the adequacy of the model. If the calculated value of F-ratio (ratio between the regression mean square and the mean square error) is higher than the tabulated value of F-ratio for response, then the model is adequate at desired significance level α. For testing the significance of individual model coefficients corresponding P-value (probability of significance that relates the risk of falsely rejecting a given hypothesis) is checked. If the P-value is less or equal to the selected α-level, then the effect of the variable is significant. If the model is adequate, the points on the normal probability plots of the residuals should form a straight line and the plots of the residuals versus the predicted response should be structure less, i.e., they should contain no obvious pattern.

Chapter 2: Literature Review

2.1 A BRIEF REVIEW OF THE WORK DONE ON THE MACHINE TOOL STRUCTURES

Lee et al. [5] have attempted and succeeded in improving the damping capacity of the column of a precision mirror surface grinding machine by designing a hybrid column made up of glass fiber reinforced epoxy composite plates adhesively bonding to a cast iron column. They have calculated the damping capacity of the newly designed column for optimizing its damping capacity. They have verified that the fiber orientation and thickness of the composite laminate plate plays important affects the damping capacity. After experiments they have found out that the damping capacity of the hybrid column was 1.35 times than the cast iron column.

For machine tools having massive slides generally do not permit rapid acceleration and deceleration during the frequent starts/stops encountered in machining. Kegg et al. [6] have used composites for the huge slides for CNC milling machine. They have constructed the vertical and horizontal slides by bonding high modulus carbon-fiber epoxy composite sandwiches to welded steel structures using adhesives for a large CNC machine. These composites structures reduced the weight of slides by 34% and 26%, respectively and increased damping by 50% to 570% without decreasing the stiffness.

Rahman et al. [7] attempted to review the some important developmental research in the area of non-conventional materials for machine tool structures. They have compared many beneficial properties of some materials for machine tool structure with the cast iron. The work suggested alternative to cast iron as material for machine tool structure so that high surface finish can be achieved with high cost effective production rate. As per the results of their studies they composite materials may be a better choice to replace conventional materials of machine tool structure.

Okuba et al. [8] have succeeded in improveing the dynamic rigidity of machine tool structures. This was achieved by employing modal analysis. This technique was successfully applied machines e.g. machining cell, an arm of automatic assembling machine and a conventional cylindrical grinder. By this they have successfully reduced chatter and achieved improved surface finish of a vertical milling machine, an NC lathe and a surface grinder.

Joint damping was increased by using epoxy resin as a bonding material between structural components of a milling machine by Chowdhury [9]. It was shown that the bonded overarm of milling machine performed much better than welded and the cast iron.

It was established experimentally by Haranath et al. [10] that applied damping treatment using viscoelastic layers can effectively increase the damping of machine. Theoretical study on the vibrations of machine tool structures with applied damping treatment by using a conventional beam element have reveled the same. Models of milling machine, radial drilling machine and lathe have been analyzed to find their natural frequency and loss factors. They have found that there is influence of layering treatment on the natural frequencies and loss factors.

Wakasawa et al. [11] have used packed with balls and successfully improved the damping capacity of machine tool structure. They found that damping characteristics changes in correspondence with the ball size and other conditions for structures closely packed with balls and the effect of ball size is the most significant factor in these structures. Excitation of structure is helpful in achieving an optimum packing ratio when the maximum damping capacity is obtained. For a 50% packing ratio, this excitation process is not necessary to obtain a stable damping capacity.

2.2 LITERATURE REVIEW ON RESEARCH DONE IN DAMPING OF COMPOSITE AND VISCOELASTIC MATERIALS

Almost for 2000 materials Lazan [12] conducted comprehensive studies and experimentation to know general nature of material damping. Lazan's results show that the logarithmic decrement values is proportional with dynamic stress.

Survey by Bert [13] and Nashif et al. [14] have revealed that the damping capacity of fibre reinforced composites and materials generally exhibit higher damping than structural metallic materials.

Viscoelasticity was used to describe the behavior of material damping of composites by Gibson et al. [15] and Sun et al. [16, 17]. Adams and his co workers [18-20], Morison [21] and Kinra et al [22] used the concept of specific damping capacity (SDC) in the damped vibration analysis.

Lin et al [23] used SDC in composites under flexural vibration using finite element method based on modal strain energy (MSE) method considering only two interlaminar stresses and neglecting transverse stress.

Ungar et.al [24] introduced the concept of damping in terms of strain energy and later was later Johnson et.al [25] applied this theory in combination with finite element analysis.

The effects of transverse shear deformation on the modal loss factors as well as the natural frequencies of composite laminated plates by using the finite element method based on the shear deformable plate theory was studied by Koo KN et al. [26].

Chandra et al. [27] has done research on damping in fiber-reinforced composite materials which involve theory behind composite damping mechanisms such as macromechanical, micromechanical and Viscoelastic approaches.

Chapter 3: Modal Analysis

3.1 INTRODUCTION

When a machine component is oscillates at its resonant frequency, it can be seen that the amplitude of vibration of that component becomes very large in course of time. Hence, while designing a machine, its knowledge of its natural frequency and mode shape is very important. The analysis to obtain the resonant frequency and the vibration mode of an elastic body is called “mode analysis” [28].

Analytical method to determine modal parameter is as follows

$$[M]\{\ddot{x}\} + [C]\{\dot{x}\} + [K]\{x\} = \{f(t)\} \qquad \text{(eq. 3.1)}$$

Here $[M]$ is the mass matrix. $[C]$ is a damping matrix. $[K]$ is the global matrix. $\{x\}$ and $\{f\}$ are the nodal displacement and force vectors respectively.

Applying Fourier transform on the on both hand sides of the eq. 3.1

$$(j\omega)^2[M]\{X(\omega)\} + (j\omega)[C]\{X(\omega)\} + [K]\{X(\omega)\} = \{F(\omega)\} \qquad \text{(eq. 3.2)}$$

where

$$\left.\begin{aligned} X(\omega) &= \int_{-\infty}^{\infty} x(t).\, e^{-j\omega t}.\, dt \\ F(\omega) &= \int_{-\infty}^{\infty} f(t).\, e^{-j\omega t}.\, dt \end{aligned}\right\} \qquad \text{(eq. 3.3)}$$

eq. 3.2 becomes

$$\Rightarrow -\omega^2[M]\{X(\omega)\} + (j\omega)[C]\{X(\omega)\} + [K]\{X(\omega)\} = \{F(\omega)\}$$

$$\Rightarrow (-\omega^2[M] + (j\omega)[C] + [K])\{X(\omega)\} = \{F(\omega)\}$$

$$\{X(\omega)\} = \frac{\{F(\omega)\}}{-\omega^2[M] + (j\omega)[C] + [K]}$$

$$\{X(\omega)\} = [H(\omega)]\{F(\omega)\} \qquad \text{(eq. 3.4)}$$

Where $H(\omega)$ is called the Transfer function matrix and i.e.

$$[H(\omega)] = \frac{1}{-\omega^2[M] + (j\omega)[C] + [K]} = [-\omega^2[M] + (j\omega)[C] + [K]]^{-1}$$

Stirring the point 'p' while measuring the response at point 'l', we get the element H_{lp} that line p but also row l in the transfer function matrix.

$$[H_{lp}] = \sum_{i=1}^{n} \frac{\emptyset_{li}\emptyset_{pi}}{-\omega^2[M_i] + (j\omega)[C_i] + [K_i]} \quad \text{(eq. 3.5)}$$

Here $\emptyset_{li}\emptyset_{pi}$ is the mode shape element on the point 'p' and 'l', that set the mode shape matrix 'φ'.

$$\varphi = [\emptyset_1, \emptyset_2, \emptyset_3, \dots \emptyset_i \dots \dots, \emptyset_n]$$

Hence

$$\varphi^T M \varphi = \begin{bmatrix} \ddots & & \\ & m_i & \\ & & \ddots \end{bmatrix}, \varphi^T C \varphi = \begin{bmatrix} \ddots & & \\ & c_i & \\ & & \ddots \end{bmatrix} \text{ and } \varphi^T K \varphi = \begin{bmatrix} \ddots & & \\ & k_i & \\ & & \ddots \end{bmatrix}$$

Where, m_i, c_i, k_i are the mass matrix, damping and stiffness matrix of mode 'i' of the system. The matrix of the transmission function of the system can be found out by uncoupling the matrix method and Fourier conversion.

$$[H_{lp}] = \sum_{i=1}^{n} \frac{\emptyset_{li}\emptyset_{pi}}{m_i[(\omega_i - \omega^2) + j2\xi_i\omega_i\omega]} \quad \text{(eq. 3.6)}$$

Where ω_i, ζ_i and $\emptyset_i$, are the mode frequencies, damping ratio and shape of mode i of the system.

3.2 CALCULATIONS OF EXCITATION FREQUENCIES THAT CAN BE OFFER MY MILLING MACHINE.

As per availability, a cuter (Side and Face Milling Cutter B 100 x 25, IS: 6308) was selected. The figure of the cutter is given below. Here B represents "straight tool". 100 stands for outer diameter of 100mm, 25 stand for the width of 25mm and finally IS: 6308 stands for the Indian Standard that the cutter conform to (i.e. Specification for side and face milling cutters).

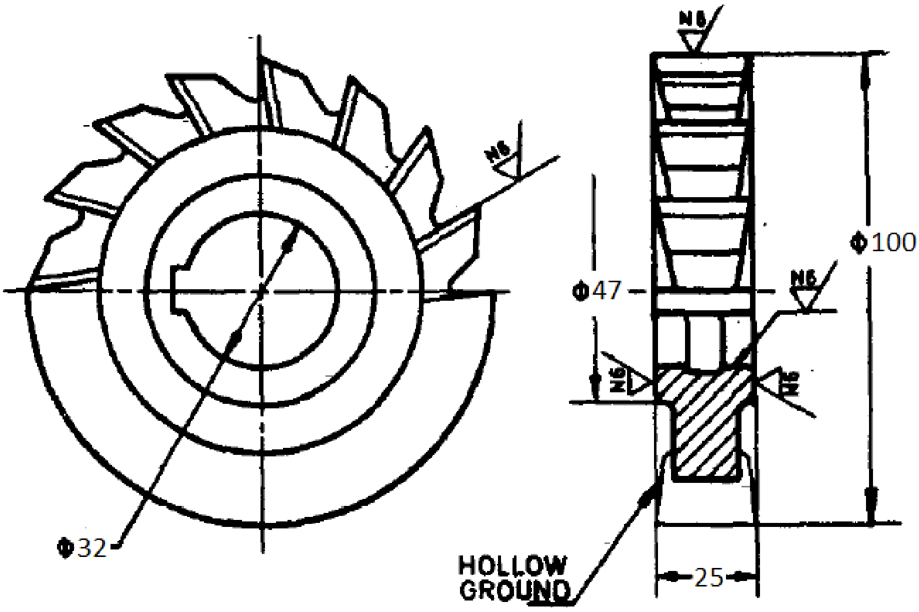


Figure 3 Geometry of cutting tool

The cutter has 26 numbers of teeth. The settings of the available RPM in the milling machine are given in the table below. The frequency ("cutting cycle per second" or "number of hits per second") is calculated based on the mentioned RPM setting and the total number of teeth of cutter.

Table 2 Excitation frequency that can be offered

Available RPM	**No of hits/ Min**	**No of hits/ Sec**
45	1170	19.5
56	1456	24.26667
71	1846	30.76667
90	2340	39
112	2912	48.53333
140	3640	60.66667
180	4680	78
224	5824	97.06667
280	7280	121.3333
355	9230	153.8333
450	11700	195
560	14560	242.6667
710	18460	307.6667
900	23400	390

Available RPM	No of hits/ Min	No of hits/ Sec
1120	29120	485.3333
1400	36400	606.6667
1800	46800	780

3.3 CALCULATIONS OF RESONANCE FREQUENCIES FOR FIVE PVC AS SECONDARY BED MATERIAL AND MS PLATE AS WORKPIECE (BY FEM BASED MODAL AND PRESTRESSED MODAL ANALYSIS)

Finite element based modal analysis helped to determine the proper cutter parameter and an indication of the precautions to be taken during the metal cutting operation. ANSYS APDL used for this purpose. A typical method of solution to the system is the Lanczos algorithm had been chosen. After computation by ANSYS, 10 modes are extracted which is represented in the images below.

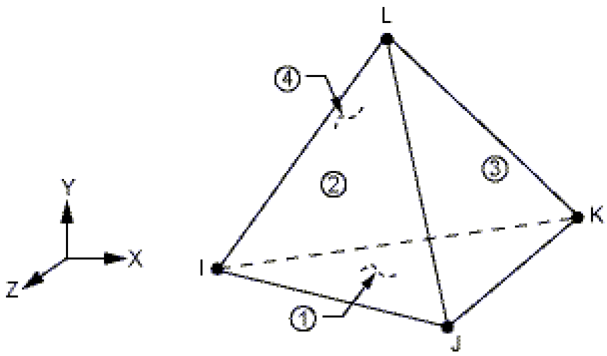


Figure 4 SOLID285 Geometry

The fine element model discritization is done by “SOLID285” element. The element is defined by four nodes having four degrees of freedom at each node; three translations in the nodal x, y, and z directions, and one hydrostatic pressure (HDSP) for all materials except nearly incompressible hyperelastic materials. The element has plasticity, hyperelasticity, creep, stress stiffening, large deflection, and large strain capabilities. It is also capable of simulating deformations of nearly incompressible elastoplastic materials, nearly incompressible hyperelastic materials, and fully incompressible hyperelastic materials [29]. The dicsritised models are given in the below mentioned figure. The material property of PVC is given in table 3.3

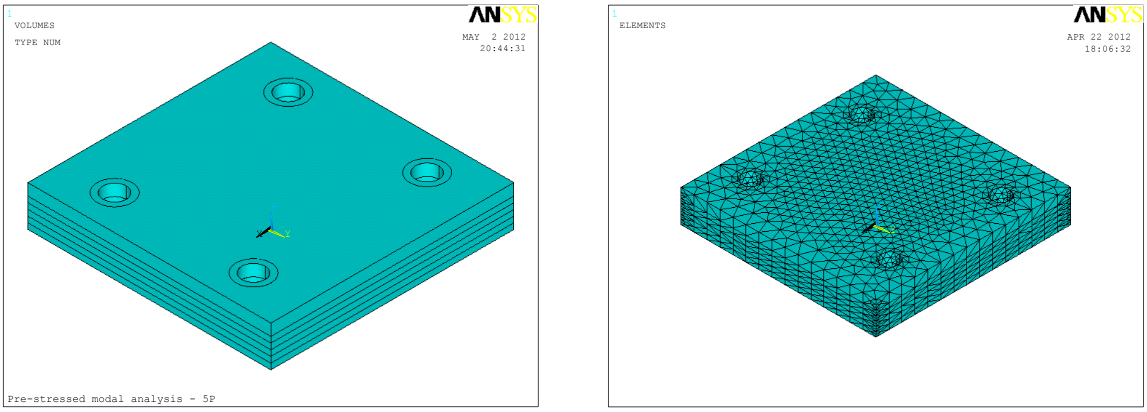


Figure 5 Unmeshed and meshed domain

The modal analyses have been carried out with and without load with following boundary condition.

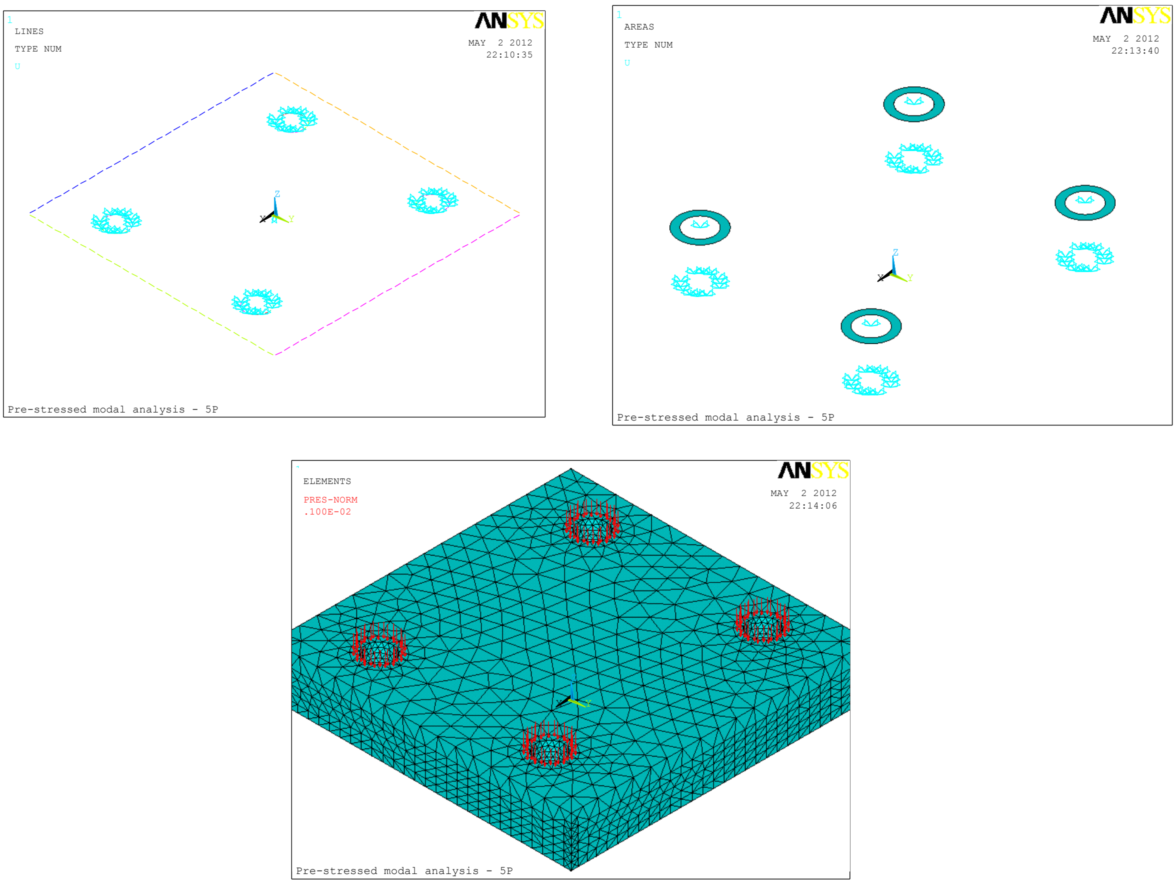
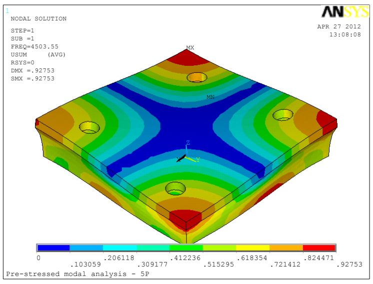
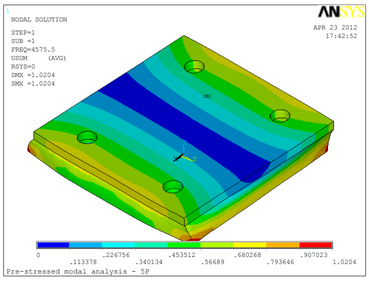
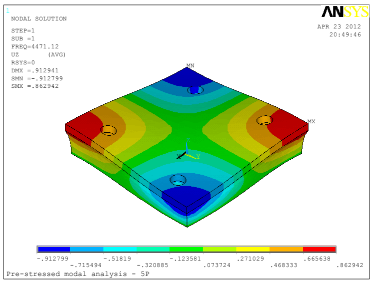
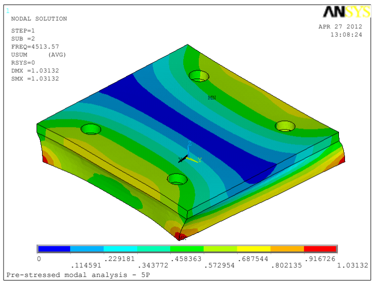
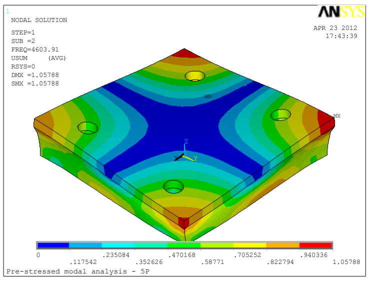
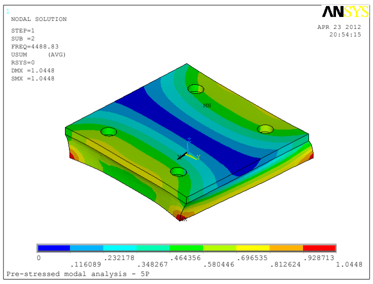
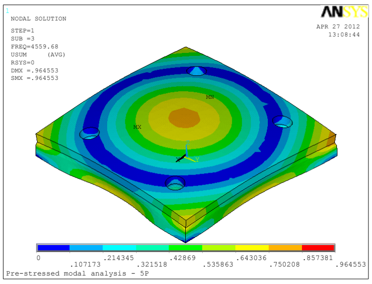
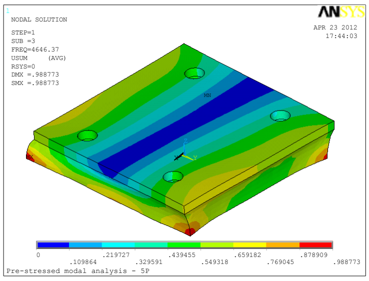
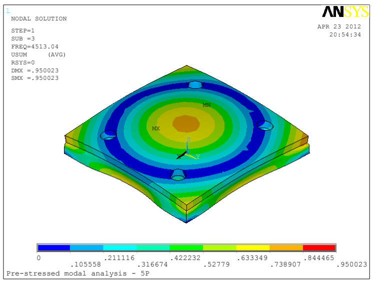
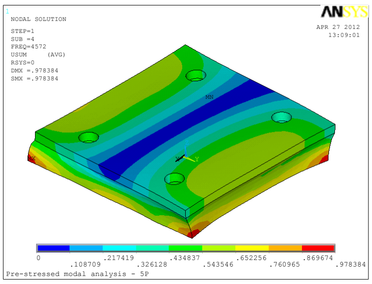
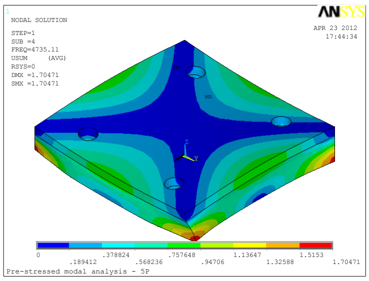
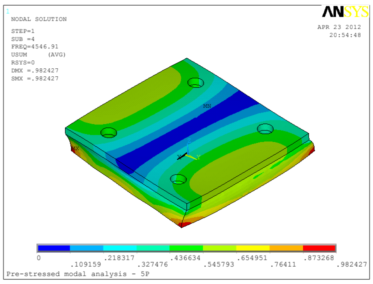
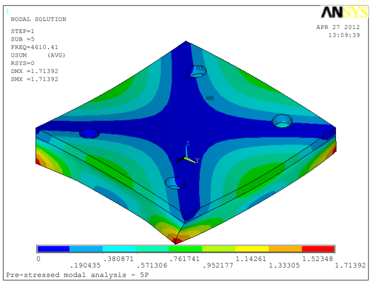
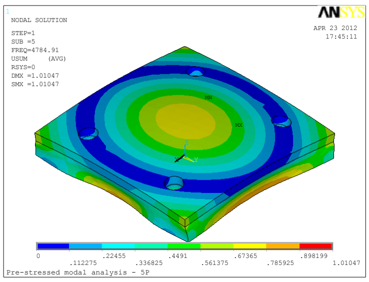
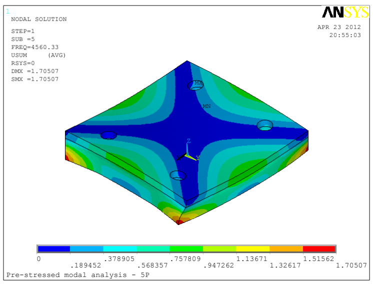


Figure 6 Applied boundary condition

The mode shapes are represented in the table below.

Table 3 Mode shapes for arrangement of 5 PVC plate and 1 MS Plate

Mode	Without any pressure	With pressure of 0.001 N/m^2	With pressure of 0.005 N/m^2
1			
2			
3			
4			
5			

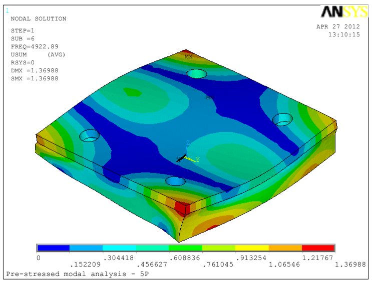
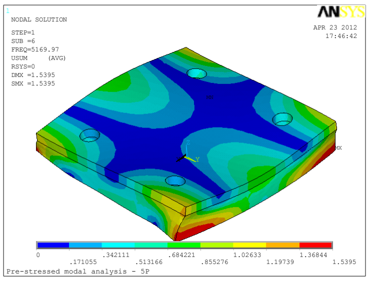
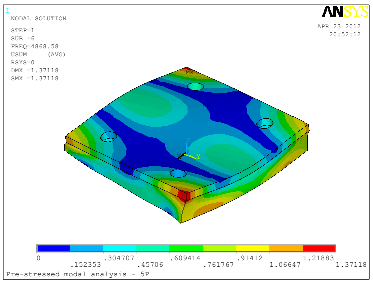
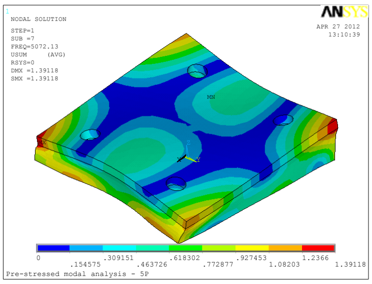
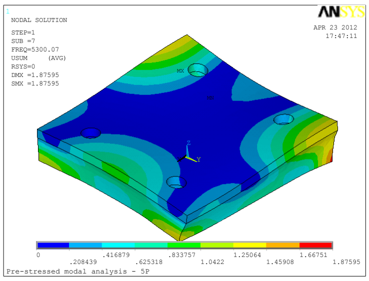
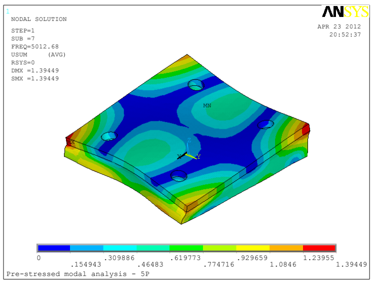
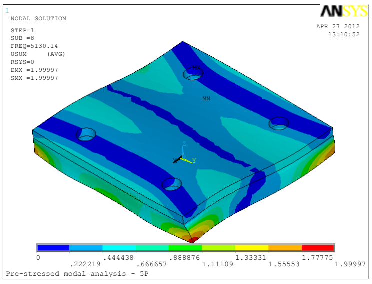
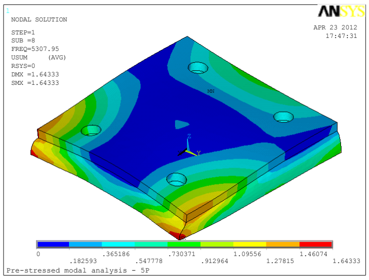
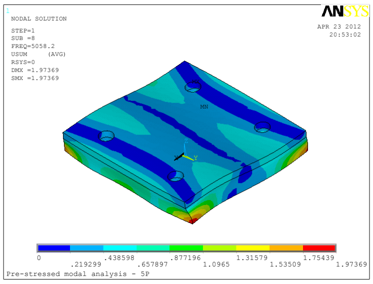
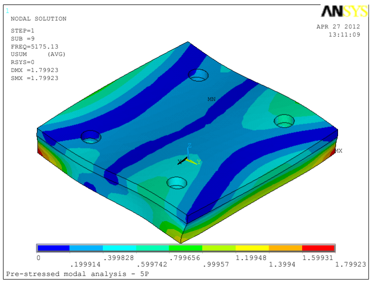
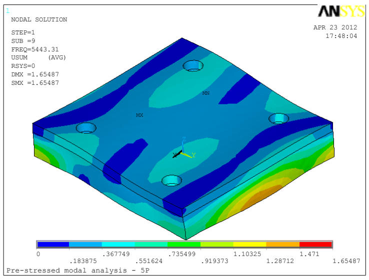
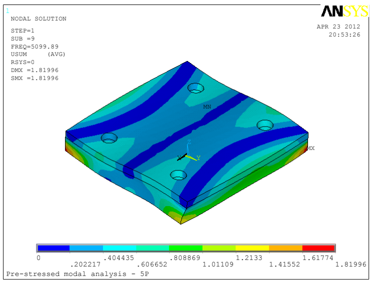
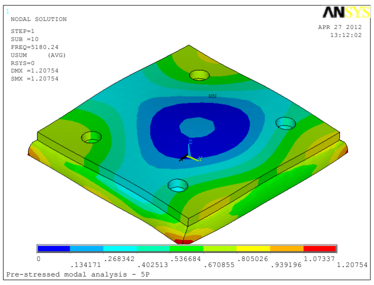
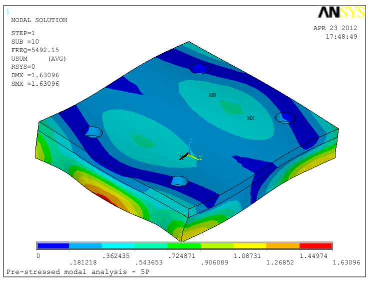
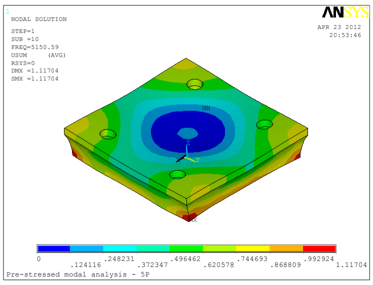
Mode	Without any pressure	With pressure of 0.001 N/m^2	With pressure of 0.005 N/m^2
6			
7			
8			
9			
10			

Table 4 Modal frequencies for arrangement of 5 PVC plate and 1 MS Plate

Mode	Without any pressure	With pressure of 0.001 N/m^2	With pressure of 0.005 N/m^2
1	4503.55	4575.5	4471.12
2	4513.57	4603.91	4488.83
3	4559.68	4646.37	4513.04
4	4572.00	4735.11	4546.91
5	4610.41	4784.91	4560.33
6	4922.89	5169.97	4868.58
7	5072.13	5300.07	5012.68
8	5130.14	5307.59	5058.2
9	5175.13	5443.31	5099.89
10	5180.24	5492.15	5150.59

Table 5 Table for mechanical properties of PVC used for simulation

Density (in g/cm3)	Young's Modulus (E , GPa)	Shear Modulus (G , GPa)	Poisson's Ratio	Yield Stress (in MPa)	UTS (in MPa)	Breaking strain (in %)	Thermal Expansion (in,10^{-6}/C)
1.4	1.5	0.6	0.42	53	60	50	75

3.4 PRECAUTIONARY CONCLUSION FOUND FROM MODAL ANALYSIS

During experimentation one of the cutters was broken unexpectedly. This phenomenon encouraged for application of modal analysis PVC (Secondary bed material) and MS Plate sandwich. As resonance frequency was not achieved during cutting, it can be concluded that the failure was catastrophic failure. But modal analysis leads to deduce following precautionary steps.

From the table it can be said that with increase in pressure the resonant frequency increases and further increase in pressure cause in reduction of natural frequency. Hence in pressure plays in important role as it changes vibration characteristics. Therefore in experiment the pressure is kept at constant level by tightening the bolts by torque wrench. Resonance frequencies found from this analysis are much higher than the excitation frequency that the milling machine along with the cutter can offer (i.e. up to 780 Hz). So three consecutive RPMs were selected arbitrarily as 180, 224 and 280 (offering 78, 97.07 and 121.33 Hz of excitation frequency) RPM.

As during machining resonance frequency was not achieved for other two secondary bed material and for all controllable parameter, no further modal analysis was necessary.

Chapter 4: Experimental details

4.1 DESIGN OF EXPERIMENT:

The design of experiments technique being a very powerful tool, helped in modelling and analysing the effect of process variables on the response variables. The response variable (or parameter of interest) is an unknown function of the process variables (or controllable parameters or as design factors).

The following four machining parameters have been used to control the milling process: depth of cut (d, mm), spindle speed (s, rpm) and feed rate (f, mm/min) and finally the number of secondary bed material used to form the sandwich on which the material to be machined (MS plate) was placed. In the present investigation these four parameters were selected as design factors while other parameter like tightening pressure have been kept constant over the experimental domain.

A Minitab generated design was used with three levels of each of the four design factors. The process variables along with their values on different levels lettings are listed as follows for four different secondary bed material materials. The number of experiment was 27 for each set of secondary bed material (PVC, PP, and GFE).

Table 6 Level setting for experiment

No of Layers of secondary bed material ‘No’	Cutter Speed ‘s’ (in RPM)	Depth of cut ‘d’ (in mm)	Feed Rate ‘f’ (in mm/Min)
1	180	0.01	16
3	224	0.02	20
5	280	0.03	25

4.2 RESPONSE VARIABLES SELECTED:

In the present study, the following two parameters have been use as response: variables: Amplitude of vibration (in mili volts as it was measured using vibration signal picked by vibration pickup and electrical signal from the vibration pickup shown in oscilloscope as RMS value), centre line average roughness (Ra, μm).

4.3 EQUIPMENT USED:

The machine used for the milling tests was a Horizontal Milling Machine (HMT FN2U) with maximum spindle speed of 1800 rpm, feed rate 800 m/min and 5.5 kW driver motor.

4.4 CUTTING TOOLS USED:

As per availability, a cuter (Side and Face Milling Cutter B 100 x 25, IS: 6308) was selected. The figure of the cutter is given below. Here B represents "straight tool". 100 stands for outer diameter of 100mm, 25 stand for the width of 25mm and finally IS: 6308 stands for the Indian Standard that the cutter conform to (i.e. Specification for side and face milling cutters). The cutter has 26 numbers of teeth.

4.5 WORKPIECE MATERIALS:

The present study was carried out with MS Plate. The chemical composition and mechanical properties of the workpiece materials are as follows. All the specimens were in the form of 210 mm × 210 mm × 10 mm blocks with four holes of 20 mm diameter shown below.

4.6 ROUGHNESS MEASUREMENT:

Roughness measurement was done by a portable stylus type profilometer, Talysurf (Taylor Hobson, Surtronic 3+). The talysurf was set to a cut-off length of 0.8 mm, traverse speed 1 mm/sec and 4 mm evaluation length, filter 2CR. Measurements, in the transverse direction, on the workpieces were repeated three times and average measurements values was recorded.

4.7 VIBRATION MEASUREMENT:

The RMS value of Amplitude of vibration was measured (in mili volts) by the vibration signal picked by vibration pickup and electrical signal from the vibration pickup recorded and shown in oscilloscope.

Figure 7 Front panel of oscilloscope

The specification of Oscilloscope is as follows.

Display: - 8x10 cm. rectangular mono-accelerator c.r.o. at 2KV e.h.t. Trace rotation by front panel present.

Vertical Deflection: - Four identical input channels ch1, ch2, ch3, ch4.

Band-width: - (-3 db) d.c. to 20 MHz (2 Hz to 20 MHz on a.c.)

Sensitivity: - 2 mV/cm to 10 V/cm in 1-2-5 sequence.

Accuracy: - ± 3 %

Variable Sensitivity: - 2.5 % 1 range allows continuous adjustment of sensitivity from 2mV/cm to V/cm.

Input impedance: - 1M/28 PF appx.

Input coupling: - D.C. and A.C.

Input protection: - 400 V d.c.

Display modes: - Single trace ch1 or ch2 or ch3 or ch4. Dual trace chopped or alternate modes automatically selected by the T.B. switch.

The specification of vibration pickup (electromechanical transducer that converting mechanical vibrations into electrical voltages) is as follows.

Figure 8 Vibration pickup

Type: -	MV-2000. Specifications:-
Dynamic frequency range: -	2 c/s to 1000 c/s
Vibration amplitude: -	±1.5 mm max.
Coil resistance: -	1000Ω
Operating temperature: -	10ċ to 40 ċ
Mounting: -	by magnet (contact type)
Dimensions: -	Cylindrical
Length: -	45 mm
Diameter: -	19 mm
Weight: -	150 gms

4.8 EXPERIMENTAL SETUP AND PROCEDURE

The stack of secondary bed material along the work-piece material was kept on the slotted table of the milling machine. Bolts were placed in the hole and tightened by the use of a torque wrench so as to keep the tightening pressure constant. After fixing the work piece

Vibration was placed on the work-piece to get the vibration signal in the oscilloscope (the other end of the cord was put to the first input port of the oscilloscope.).

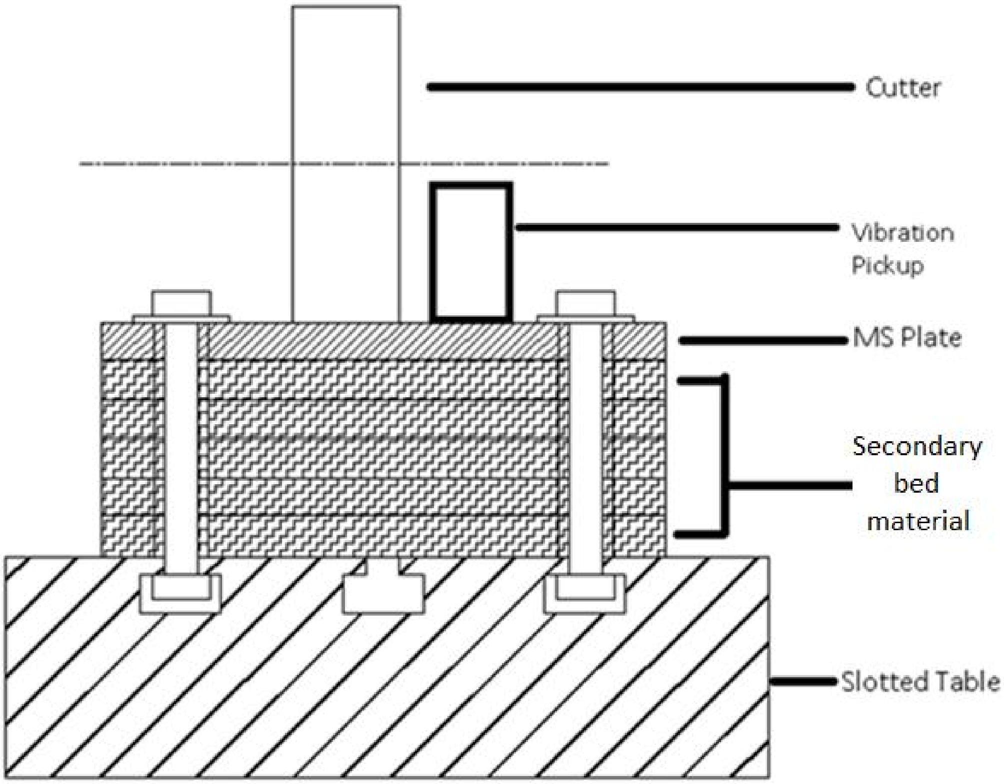


Figure 9 Experimental setup

Then the machining (up milling) was done. After machining of MS plate the surface roughness was measured in the Talysurf. Measurements, in the transverse direction, on the workpieces were repeated three times and an average measurements value was recorded. The experiment (measurement of vibration amplitude and surface roughness) is repeated for different sets of secondary bed material by decreasing the number.

Table 7 Experimental detail

For Secondary bed material →							PP		PVC		GFE	
RunOrder	PtType	Blocks	S (in RPM)	f (in mm/min)	d (in mm)	n (in Piece)	Amp (in mV)	Ra (μ mtrs)	Amp (in mV)	Ra (μ mtrs)	Amp (in mV)	Ra (μ mtrs)
1	2	1	224	20	0.01	5	9.513	1.52	9.800	1.63	42.058	2.70
2	2	1	180	20	0.02	5	7.813	1.30	14.100	1.47	38.389	2.00
3	2	1	224	16	0.02	5	13.737	1.00	18.200	1.00	41.300	2.60
4	2	1	224	25	0.02	5	10.736	1.20	22.600	1.19	38.200	2.40
5	2	1	280	20	0.02	5	9.937	1.30	20.500	1.65	36.400	2.40
6	2	1	224	20	0.03	5	12.230	0.80	25.300	0.64	37.500	2.54
7	2	1	180	20	0.01	3	13.312	1.95	9.500	1.70	18.930	0.80
8	2	1	224	16	0.01	3	11.910	1.60	17.900	1.30	20.100	1.20
9	2	1	224	25	0.01	3	21.230	1.23	16.600	1.29	21.600	1.60
10	2	1	280	20	0.01	3	11.123	1.55	20.400	1.64	20.400	1.50
11	2	1	180	16	0.02	3	13.785	1.50	14.647	1.46	21.800	0.80
12	2	1	180	25	0.02	3	14.988	2.00	20.100	1.76	24.300	1.00
13	0	1	224	20	0.02	3	11.820	1.95	25.400	1.66	28.600	1.93
14	0	1	224	20	0.02	3	12.512	2.00	24.300	1.77	28.970	2.00
15	0	1	224	20	0.02	3	11.169	1.89	26.600	1.56	29.900	2.00
16	2	1	280	16	0.02	3	17.121	1.81	28.200	1.67	19.800	1.10
17	2	1	280	25	0.02	3	17.700	1.60	26.100	1.38	24.700	1.80
18	2	1	180	20	0.03	3	12.987	1.62	22.400	1.78	27.300	1.50
19	2	1	224	16	0.03	3	22.800	1.20	27.200	1.06	26.300	1.80
20	2	1	224	25	0.03	3	17.531	1.80	30.600	1.43	30.600	2.20
21	2	1	280	20	0.03	3	21.100	1.90	28.300	1.68	24.300	1.80
22	2	1	224	20	0.01	1	15.864	0.90	17.400	0.75	11.600	0.80
23	2	1	180	20	0.02	1	12.930	1.70	10.900	1.69	17.900	0.60
24	2	1	224	16	0.02	1	15.300	1.20	19.500	0.92	14.900	0.90
25	2	1	224	25	0.02	1	22.300	1.40	24.100	1.13	23.490	1.80
26	2	1	280	20	0.02	1	18.400	1.60	26.000	1.53	18.100	1.40
27	2	1	224	20	0.03	1	19.100	1.75	21.100	1.66	27.600	2.00

Chapter 5: Result and discussion

The influences of the cutting parameters (d, s, n and f) on the response variables selected have been assessed for three different secondary bed materials by conducting experiments as outlined in section of experimentation. The results are put into the Minitab software for further analysis following the steps outlined in same section. The second-order model was derived in obtaining the empirical relationship between the two response parameters [RMS amplitude of vibration (Amp) surface roughness parameters (Ra)] and the machining variables (d, s, n and f). The analysis of variance (ANOVA) has been used to check the adequacy of the second order model. The results for the three different secondary bed materials are presented one by one

5.1 RESULTS AND ANALYSIS FOR POLYPROPYLENE (PP) AS SECONDARY BED MATERIAL:

The complete results from the 27 machining trials for PP as secondary bed material performed as per the experimental plan are shown in Table 4.1. By using Minitab software the data are analysed to obtain second-order response surface equations fitted for all the two response variables (Amp & Ra) as mentioned below.

Amp = 58.9794 - 0.0456072*S - 5.01971*f - 366.796*d + 5.80548*n + 0.186235*f2 + 25109.9*d2 + 5.19220*S*d - 0.00847500*S*n - 80.3836*f*d - 0.275395*f*n (eq. 5.1)

Ra= -7.01930 + 0.00847320*S + 0.650597*f - 29.5244*d + 1.08578*n - 0.0138145*f2 - 2331.58*d2 - 0.125477*n2 - 7.75081*10-04*S*f + 0.333756*S*d + 5.40002*f*d – 19.6250*d*n (eq. 5.2)

The ANOVA have been performed to check whether the model is adequate as well as to check the significance of the individual model coefficients. The ANOVA table for only Amp is presented here.

Table 8 ANOVA for second order model for Amp in milling for PP as secondary bed material

Source	DF	Seq SS	Adj SS	Adj SS	F	P
Regression	10	409.136	409.136	45.460	34.28	0.000
Linear	4	217.970	228.215	57.054	210.26	0.000
Square	2	109.029	109.029	54.515	200.90	0.000
Interaction	4	107.922	107.922	26.980	99.43	0.000
Residual Error	17	22.545	22.545	1.326		
Lack-of-Fit	14	3.439	3.439	0.246	0.54	0.804
Pure Error	2	0.902	0.902	0.451		
Total	26	431.681				

It can be appreciated that the P-value is less than 0.05 which means that the model is significant at 95% confidence level. The ANOVA table for the second-order model proposed for Amp given in Eq. is as follows

Table 9 ANOVA for model coefficients for Amp in milling for PP as secondary bed material

Source	DF	Seq SS	Adj SS	Adj SS	F	P
S	1	29.32	32.531	32.531	119.89	0
f	1	12.491	8.056	8.056	29.69	0
d	1	43.305	39.209	39.209	144.5	0
n	1	132.854	148.419	148.419	546.97	0
f*f	1	68.696	88.167	88.167	324.92	0
d*d	1	40.333	40.333	40.333	148.64	0
S*d	1	27.553	27.217	27.217	100.3	0
S*n	1	2.826	2.901	2.901	10.69	0.005
f*d	1	52.768	52.768	52.768	194.47	0
f*n	1	24.775	24.775	24.775	91.3	0

Above table shows the ANOVA table for individual model coefficients where it can be noticed that all effects with a P-value less than 0.05 which means that they are significant at 95% confidence level. The main effect plot for secondary bed material PP is as follows.

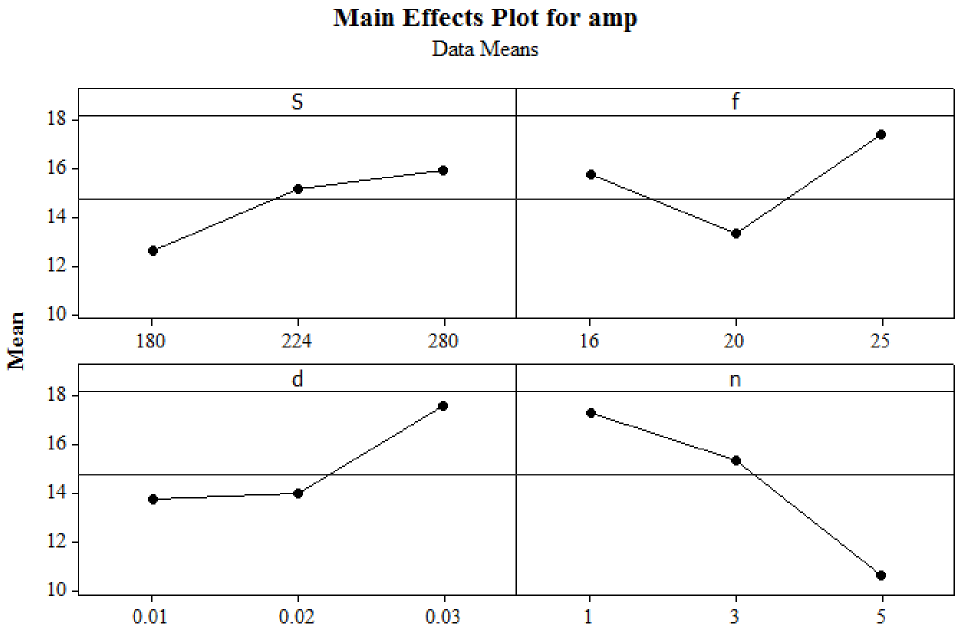


Figure 10 Main effect plot for PP as SBM (for Amp)

The normal probability plot of the residuals and the plot of residuals versus the predicted response for Amp are shown below. A check on the probability plot of the shows that, the residuals fall on or near a straight line.

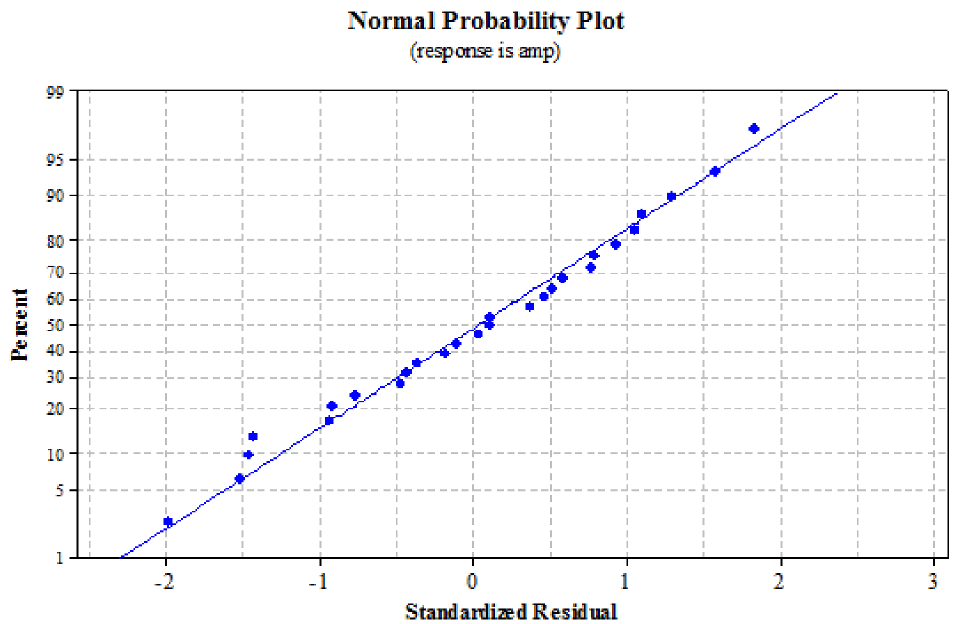


Figure 11 Normal probability plot for PP as SBM (for Amp)

This refers that the errors are distributed normally. Also residuals versus the predicted response plot reveal that there is no obvious pattern and unusual structure. This implies that the model proposed is adequate. The ANOVA table for only Ra is presented here.

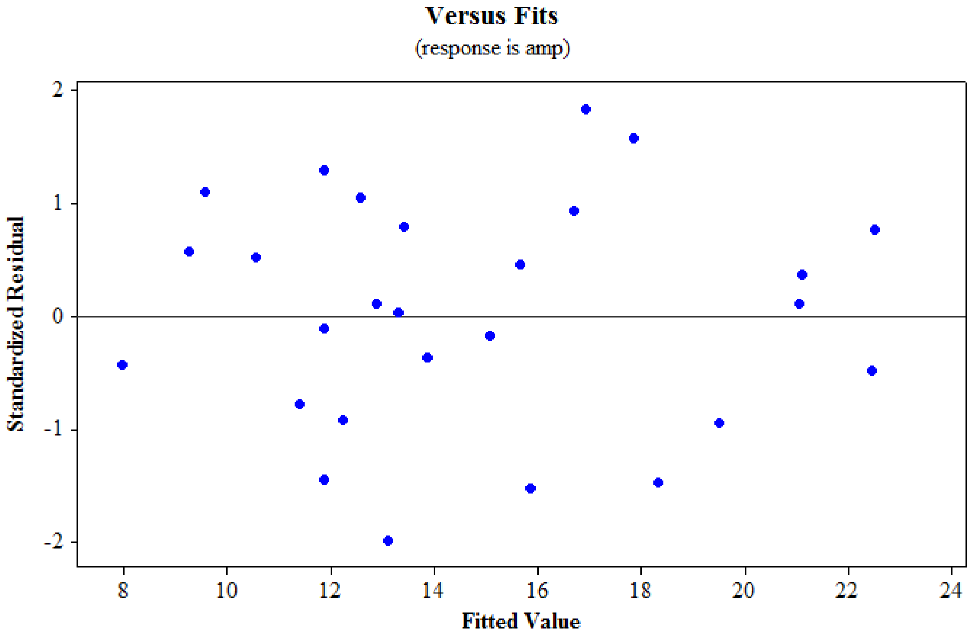


Figure 12 Residual versus predicted response for PP as SBM for (Amp)

Table 10 ANOVA for second order model for Ra in milling for PP as secondary bed material

Source	DF	Seq SS	Adj SS	Adj SS	F	P
Regression	11	3.01841	3.01841	0.2744	90.39	0
Linear	4	0.23748	0.27301	0.06825	22.48	0
Square	3	1.69171	1.69416	0.56472	186.03	0
Interaction	4	1.08922	1.08922	0.2723	89.7	0
Residual Error	15	0.04554	0.04554	0.00304		
Lack-of-Fit	13	0.03947	0.03947	0.00304	1	0.605
Pure Error	2	0.00607	0.00607	0.00303		
Total	26	3.06394				

It can be appreciated that the P-value is less than 0.05 which means that the model is significant at 95% confidence level. The ANOVA table for the second-order model proposed for Ra given in Eq. is as follows.

Table 11 ANOVA for model coefficients for Ra in milling for PP as secondary bed material

Source	DF	Seq SS	Adj SS	Adj SS	F	P
S	1	0.00143	0.0163	0.0163	5.37	0.035
f	1	0.05711	0.04632	0.04632	15.26	0.001
d	1	0.00853	0.03901	0.03901	12.85	0.003
n	1	0.17041	0.17041	0.17041	56.14	0
f*f	1	0.11041	0.45484	0.45484	149.83	0
d*d	1	0.07336	0.32591	0.32591	107.36	0
n*n	1	1.50794	1.51026	1.51026	497.5	0
S*f	1	0.12383	0.12383	0.12383	40.79	0
S*d	1	0.11103	0.11246	0.11246	37.05	0
f*d	1	0.23814	0.23814	0.23814	78.45	0
d*n	1	0.61622	0.61622	0.61622	202.99	0

Above table shows the ANOVA table for individual model coefficients where it can be noticed that all effects with a P-value less than 0.05 which means that they are significant at 95% confidence level. The main effect plot for secondary bed material PP is as follows.

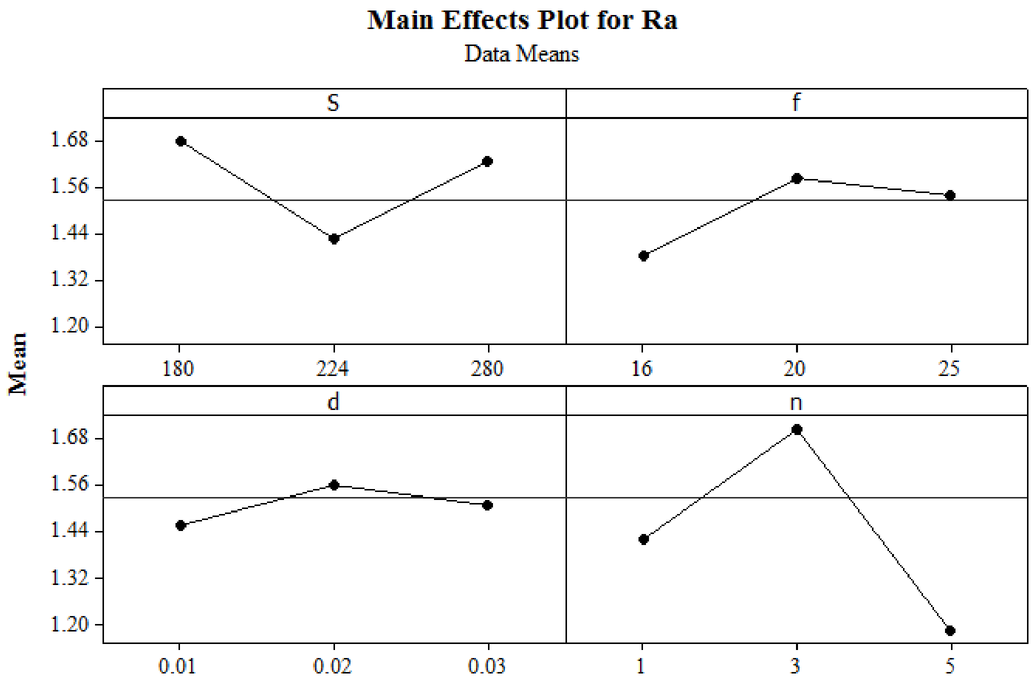


Figure 13 Main effect plot for PP as SBM (for Ra)

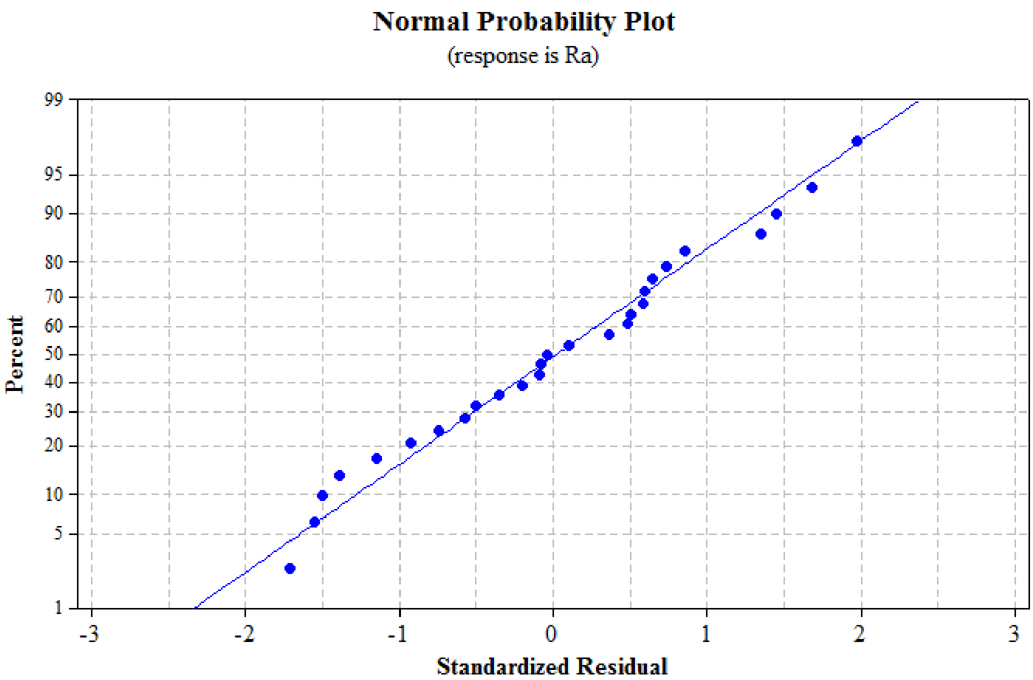


Figure 14 Normal probability plot for PP as SBM (for Ra)

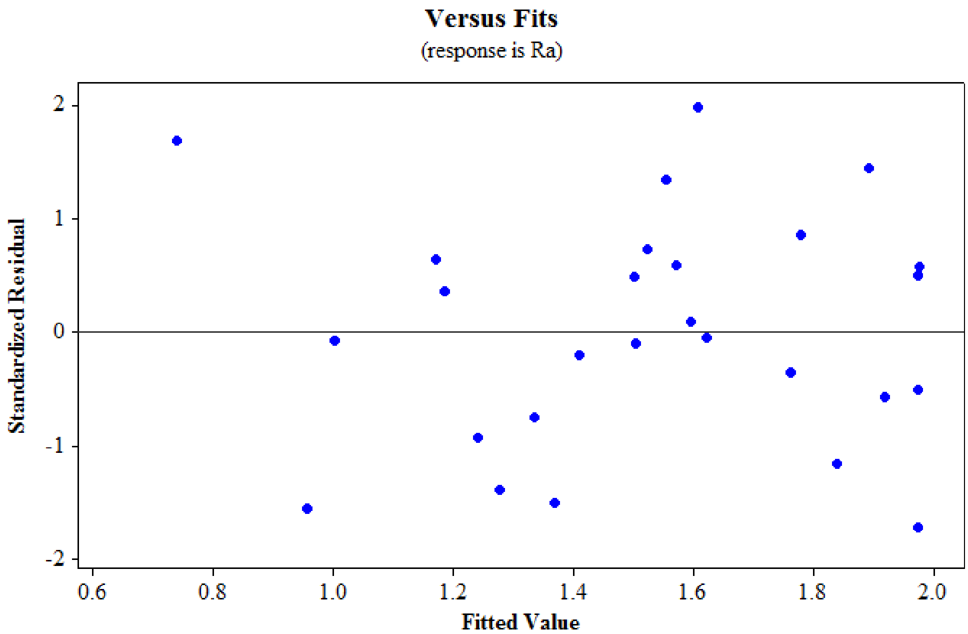


Figure 15 Residual versus predicted response for PP as SBM for (Ra)

The normal probability plot of the residuals and the plot of residuals versus the predicted response for Ra are shown. A check on the probability plot of the shows that, the residuals fall on or near a straight line. This refers that the errors are distributed normally.

Also residuals versus the predicted response plot reveal that there is no obvious pattern and unusual structure. This implies that the model proposed is adequate.

5.2 RESULTS AND ANALYSIS FOR POLYVINYLCHLORIDE (PVC) AS SECONDARY BED MATERIAL

The complete results from the 27 machining trials for PVC as secondary bed material performed as per the experimental plan are shown in Table 4.1. By using Minitab software the data are analysed to obtain second-order response surface equations fitted for all the two response variables (Amp & Ra) as mentioned below.

Amp = -151.892 + 1.05059*S + 1.62522*f + 1038.91*d + 8.24003*n - 0.00145804*S2 - 23491.7*d2 - 1.11854*n2 - 0.00841250*f*S - 2.48331*S*d - 0.0213847*S*n + 27.1233*f*d + 147.500*d*n (eq. 5.3)

Ra= -5.05159 - 0.0250697*S + 0.706715*f + 91.1484*d + 0.945723*n - 0.0141065*f2 + 8.34416*10-05*S2 - 1540.93*d2 - 0.0791482*n2 - 6.85789*10-04*S*f + 2.04490*f*d -23.7500*d*n (eq. 5.4)

The ANOVA have been performed to check whether the model is adequate as well as to check the significance of the individual model coefficients. The ANOVA table for only Amp is presented here.

Table 12 ANOVA for second order model for Amp in milling for PVC as secondary bed material

Source	DF	Seq SS	Adj SS	Adj SS	F	P
Regression	12	867.56	867.56	72.297	69.75	0
Linear	4	625.197	600.3	150.075	144.8	0
Square	3	162.209	162.434	54.145	52.24	0
Interaction	5	80.153	80.153	16.031	15.47	0
Residual Error	14	14.51	14.51	1.036		
Lack-of-Fit	12	11.864	11.864	0.989	0.75	0.701
Pure Error	2	2.647	2.647	1.323		
Total	26	882.07				

It can be appreciated that the P-value is less than 0.05 which means that the model is significant at 95% confidence level. The ANOVA table for the second-order model proposed for Amp given in Eq. is as follows

Table 13 ANOVA for model coefficients for Amp in milling for PVC as secondary bed material

Source	DF	Seq SS	Adj SS	Adj SS	F	P
f	1	21.039	12.996	12.996	12.54	0.003
S	1	264.23	258.743	258.743	249.64	0
d	1	333.908	321.37	321.37	310.07	0
n	1	6.021	9.107	9.107	8.79	0.01
S*S	1	32.804	76.836	76.836	74.13	0
d*d	1	9.603	33.089	33.089	31.92	0
n*n	1	119.802	120.027	120.027	115.8	0
f*S	1	14.587	14.587	14.587	14.07	0.002
f*d	1	6.062	6.008	6.008	5.8	0.03
S*d	1	6.226	6.226	6.226	6.01	0.028
S*n	1	18.468	18.468	18.468	17.82	0.001
d*n	1	34.81	34.81	34.81	33.59	0

Above table shows the ANOVA table for individual model coefficients where it can be noticed that all effects with a P-value less than 0.05 which means that they are significant at 95% confidence level. The main effect plot for secondary bed material PVC is as follows.

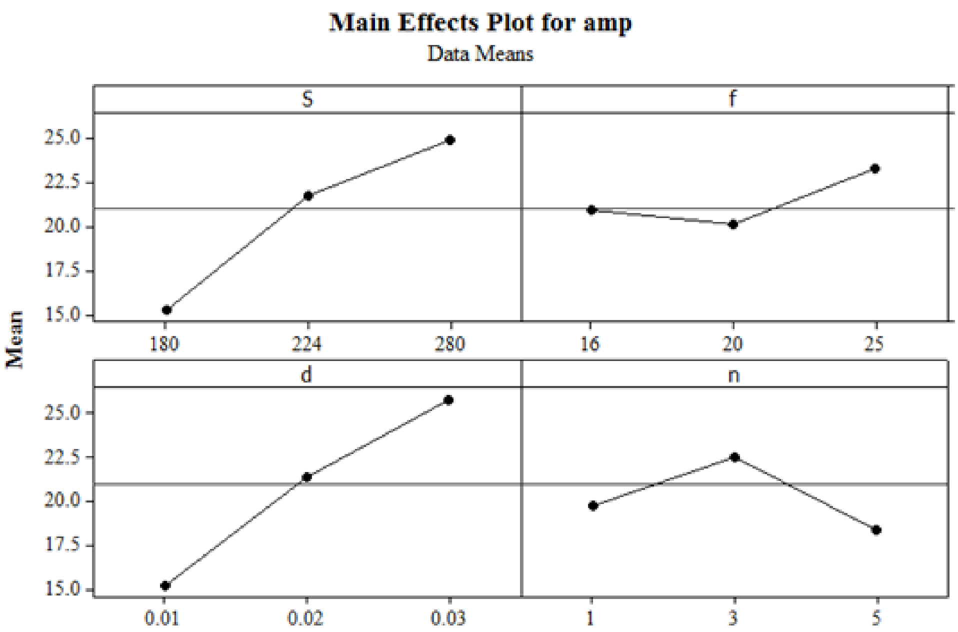


Figure 16 Main effect plot for PVC as SBM (for Amp)

The normal probability plot of the residuals and the plot of residuals versus the predicted response for Amp are shown below.

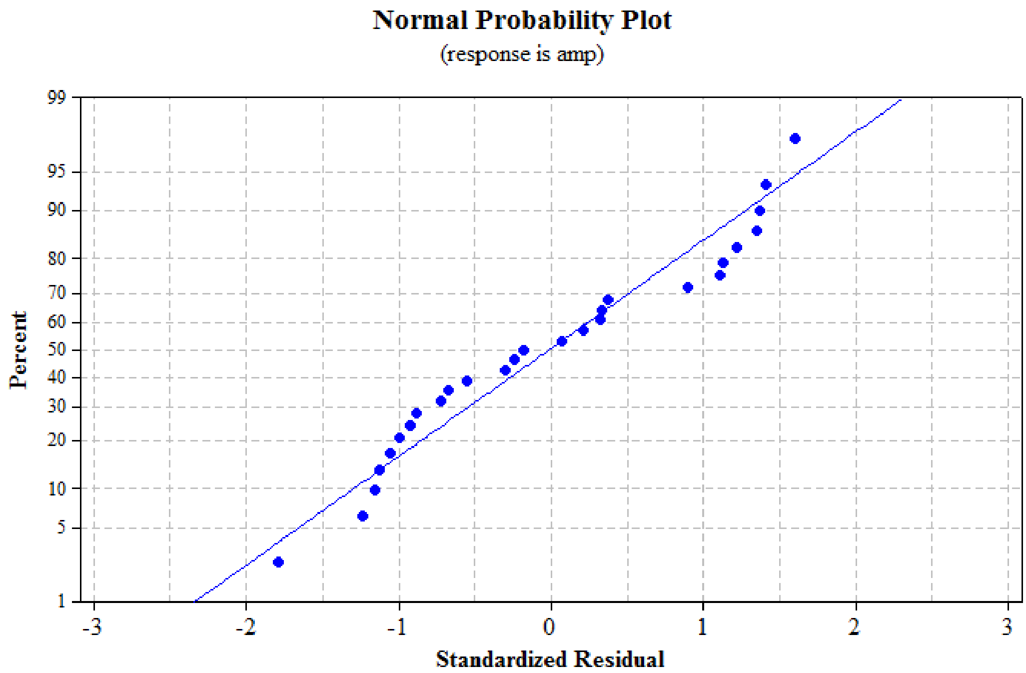


Figure 17 Normal probability plot for PVC as SBM (for Amp)

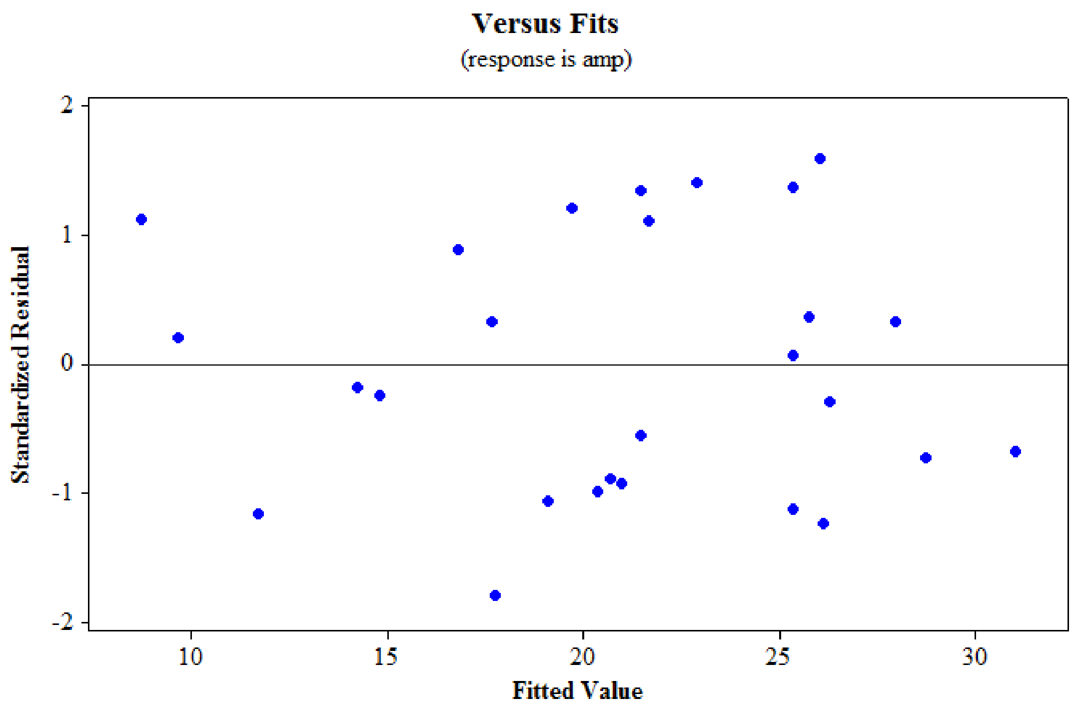


Figure 18 residual versus predicted response for PVC as SBM (for Amp)

A check on the probability plot of the shows that, the residuals fall on or near a straight line. This refers that the errors are distributed normally. Also residuals versus the predicted response plot reveal that there is no obvious pattern and unusual structure. This implies that the model proposed is adequate.

The ANOVA table for only Ra is presented here.

Table 14 ANOVA for second order model for Ra in milling for PVC as secondary bed material

Source	DF	Seq SS	Adj SS	Adj SS	F	P
Regression	11	2.62201	2.62201	0.238364	33.52	0
Linear	4	0.03158	0.0497	0.012424	1.75	0.192
Square	4	1.55683	1.5584	0.389601	54.79	0
Interaction	3	1.03359	1.03359	0.34453	48.45	0
Residual Error	15	0.10666	0.10666	0.007111		
Lack-of-Fit	13	0.08459	0.08459	0.006507	0.59	0.778
Pure Error	2	0.02207	0.02207	0.011033		
Total	26	2.72867				

It can be appreciated that the P-value is less than 0.05 which means that the model is significant at 95% confidence level. The ANOVA table for the second-order model proposed for Ra given in Eq. is as follows.

Table 15 ANOVA for model coefficients for Ra in milling for PVC as secondary bed material

Source	DF	Seq SS	Adj SS	Adj SS	F	P
f	1	0.03039	0.03163	0.03163	4.45	0.052
S	1	0.00006	0.0164	0.016397	2.31	0.05
d	1	0.0003	0.00004	0.000039	0.01	0.942
N	1	0.00083	0.00083	0.000833	0.12	0.737
f*f	1	0.34638	0.4222	0.422201	59.38	0
S*S	1	0.66303	0.22401	0.224014	31.5	0
d*d	1	0.01402	0.12664	0.126637	17.81	0.001
n*n	1	0.53341	0.53456	0.534562	75.18	0
f*S	1	0.09694	0.09694	0.096941	13.63	0.002
f*d	1	0.03415	0.03415	0.03415	4.8	0.045
d*n	1	0.9025	0.9025	0.9025	126.92	0

Above table shows the ANOVA table for individual model coefficients where it can be noticed that all effects (except Linear terms) with a P-value less than 0.05. As the square terms are have P-value less than 0.05, linear terms must be considered. The main effect plot for secondary bed material PVC is as follows.

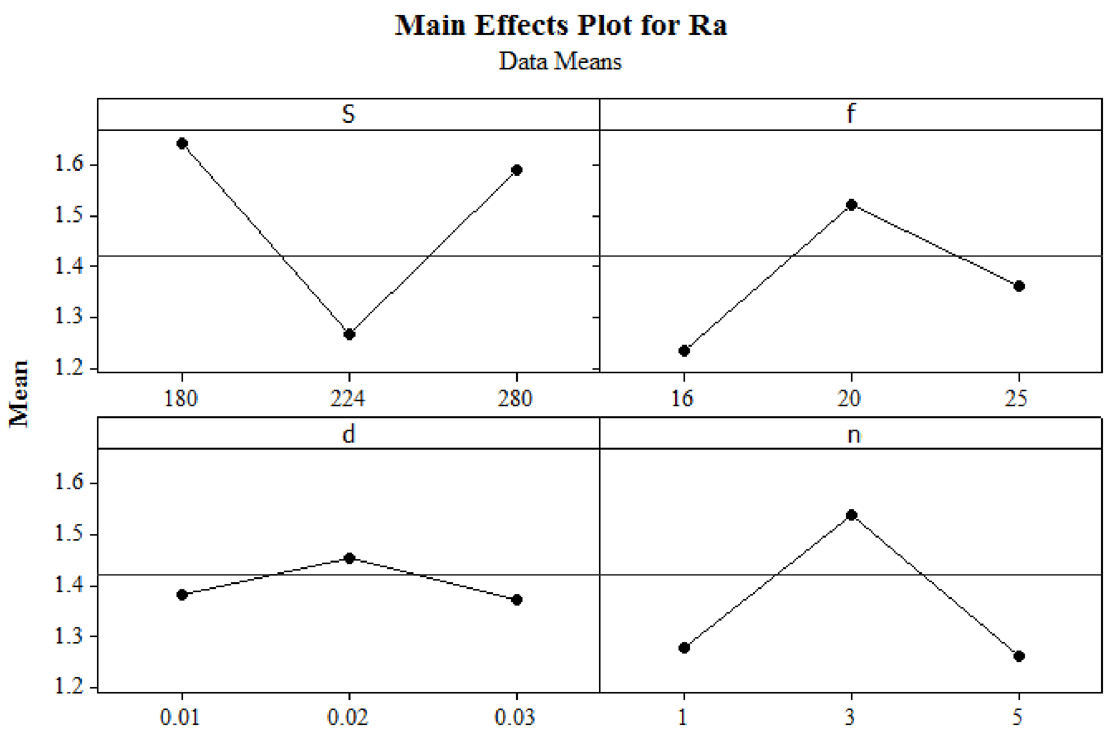


Figure 19 Main effect plot for PVC as SBM (for Ra)

The normal probability plot of the residuals and the plot of residuals versus the predicted response for Ra are shown. A check on the probability plot of the shows that, the residuals fall on or near a straight line. This refers that the errors are distributed normally. Also residuals versus the predicted response plot reveal that there is no obvious pattern and unusual structure. This implies that the model proposed is adequate.

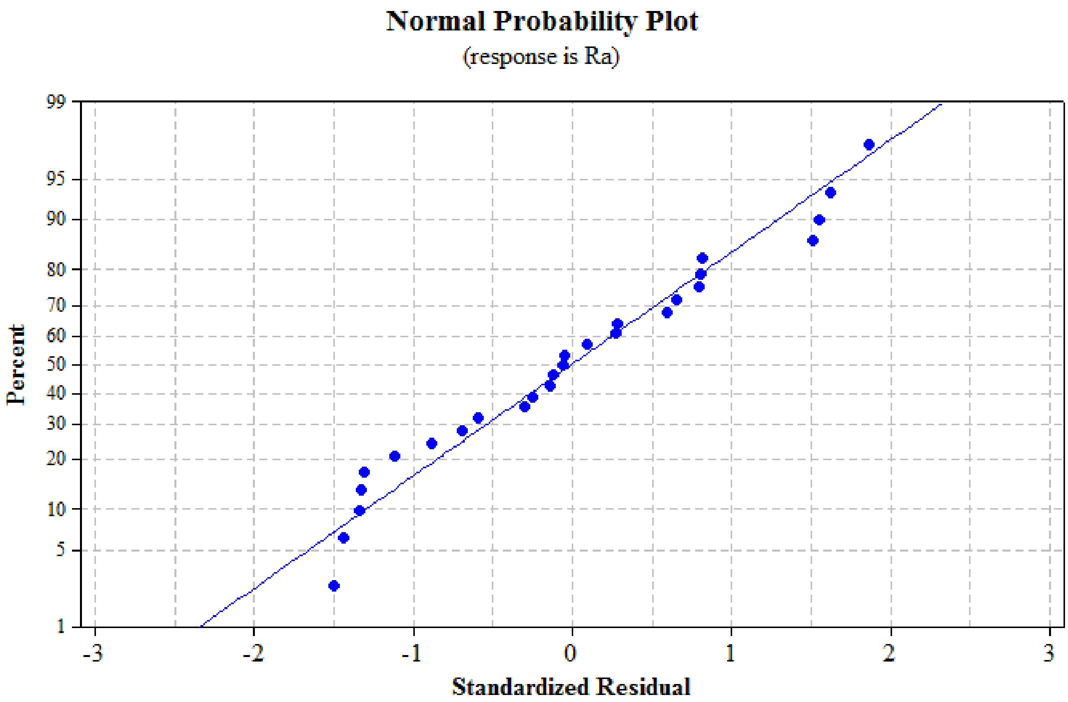


Figure 20 Normal probability plot for PVC as SBM (for Ra)

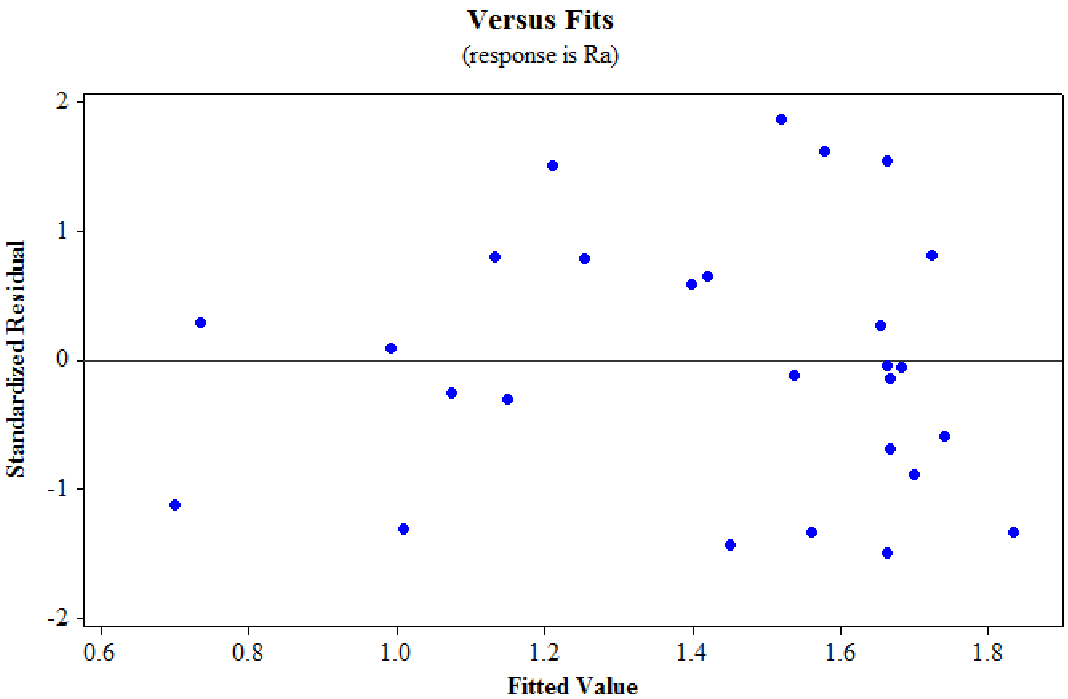


Figure 21 Residual versus predicted response for PVC as SBM for (Ra)

5.3 RESULTS AND ANALYSIS FOR GLASS FIBER EPOXY (GFE) AS SECONDARY BED MATERIAL

The complete results from the 27 machining trials for PVC as secondary bed material performed as per the experimental plan are shown in Table 4.1. By using Minitab software the data are analysed to obtain second-order response surface equations fitted for all the two response variables (Amp & Ra) as mentioned below.

Amp = -179.845 + 0.809274*S + 6.12247*f + 2143.35*d + 12.5281*n - 0.125688* f2 - 0.00167934*S2 - 21909.6*d2 + 0.675667*n2 - 2.24878*S*d + 16.6833*f*d - 256.975*d*n - 0.318936*f*n (eq. 5.5)

Ra= -20.8128 + 0.107521*S + 0.513883*f + 151.067*d + 1.26318*n - 0.0122778*f2 - 2.30858*10-04*S2 - 680.551*d2 + 0.0361112*n2 - 0.202853*S*d + 0.000556416*S*f - 17.0000*d*n - 0.0305998*f*n - 9.96672*10-04*S*n (eq.5.6)

The ANOVA have been performed to check whether the model is adequate as well as to check the significance of the individual model coefficients. The ANOVA table for only Amp is presented here.

Table 16 ANOVA for second order model for Amp in milling for GFE as secondary bed material

Source	DF	Seq SS	Adj SS	Adj SS	F	P
Regression	12	1741.41	1741.41	145.12	281.09	0
Linear	4	1361.9	1286.41	321.6	622.93	0
Square	4	233.22	233.22	58.3	112.93	0
Interaction	4	146.29	146.29	36.57	70.84	0
Residual Error	14	7.23	7.23	0.52		
Lack-of-Fit	12	6.33	6.33	0.53	1.18	0.549
Pure Error	2	0.9	0.9	0.45		
Total	26	1748.64				

It can be appreciated that the P-value is less than 0.05 which means that the model is significant at 95% confidence level. The ANOVA table for the second-order model proposed for Amp given in Eq. is as follows

Table 17 ANOVA for model coefficients for Amp in milling for GFE as secondary bed material

Source	DF	Seq SS	Adj SS	Adj SS	F	P
f	1	25.35	29.11	29.11	56.38	0
S	1	5.23	2.02	2.02	3.91	0.068
d	1	126.18	119.29	119.29	231.05	0
n	1	1205.15	1136	1136	2200.39	0
f*f	1	21.33	33.52	33.52	64.92	0
S*S	1	115.57	90.74	90.74	175.75	0
d*d	1	57.36	25.6	25.6	49.59	0
n*n	1	38.96	38.96	38.96	75.46	0
f*d	1	2.3	2.27	2.27	4.4	0.055
f*n	1	33.23	33.23	33.23	64.36	0
S*d	1	5.11	5.11	5.11	9.89	0.007
d*n	1	105.66	105.66	105.66	204.65	0

Above table shows the ANOVA table for individual model coefficients where it can be noticed that all effects (except S & f*d) with a P-value less than 0.05 which means that they are significant at 95% confidence level. As the P-Value of S & f*d are very near to 0.05 they are taken as significant. The main effect plot for secondary bed material GFE is as follows. The normal probability plot of the residuals and the plot of residuals versus the predicted response for Amp are shown. A check on the probability plot of the shows that, the residuals fall on or near a straight line. This refers that the errors are distributed normally. Also residuals versus the predicted response plot reveal that there is no obvious pattern and unusual structure. This implies that the model proposed is adequate.

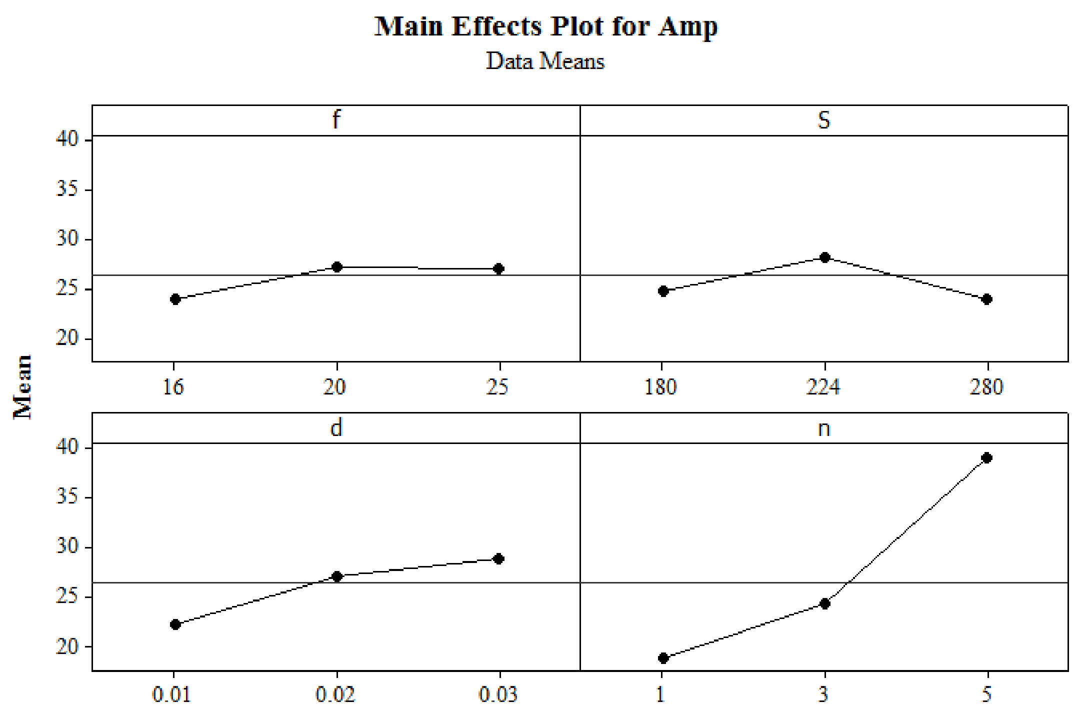


Figure 22 Main effect plot for GFE as SBM (for AMP)

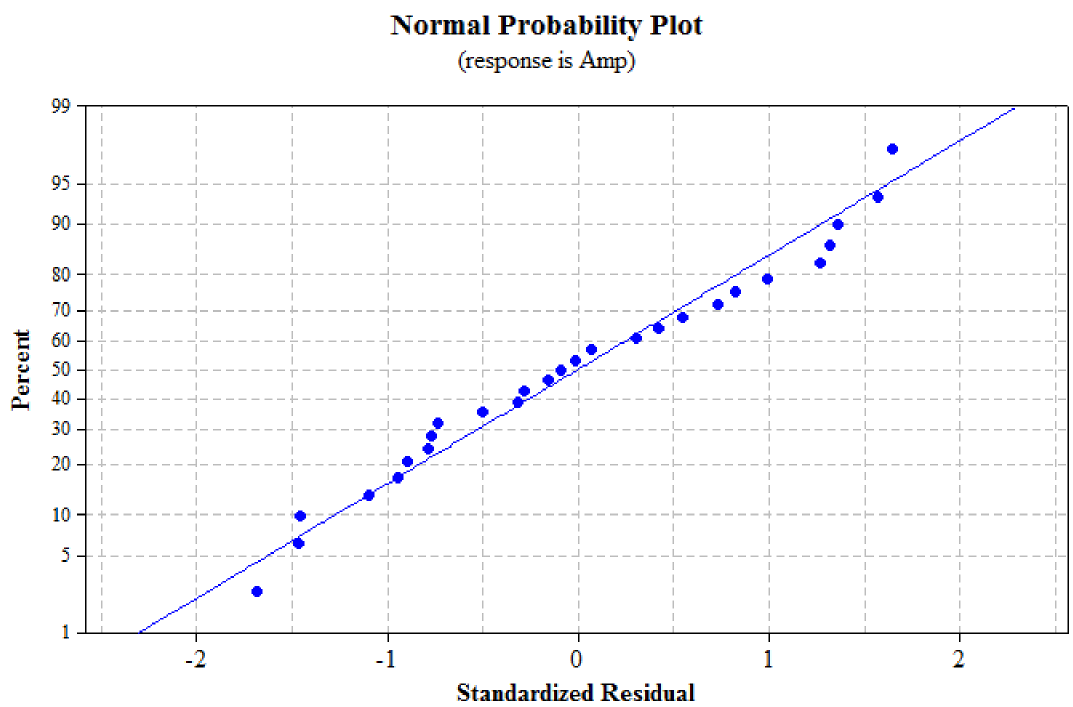


Figure 23 normal probability plot for GFE as SBM (for Amp)

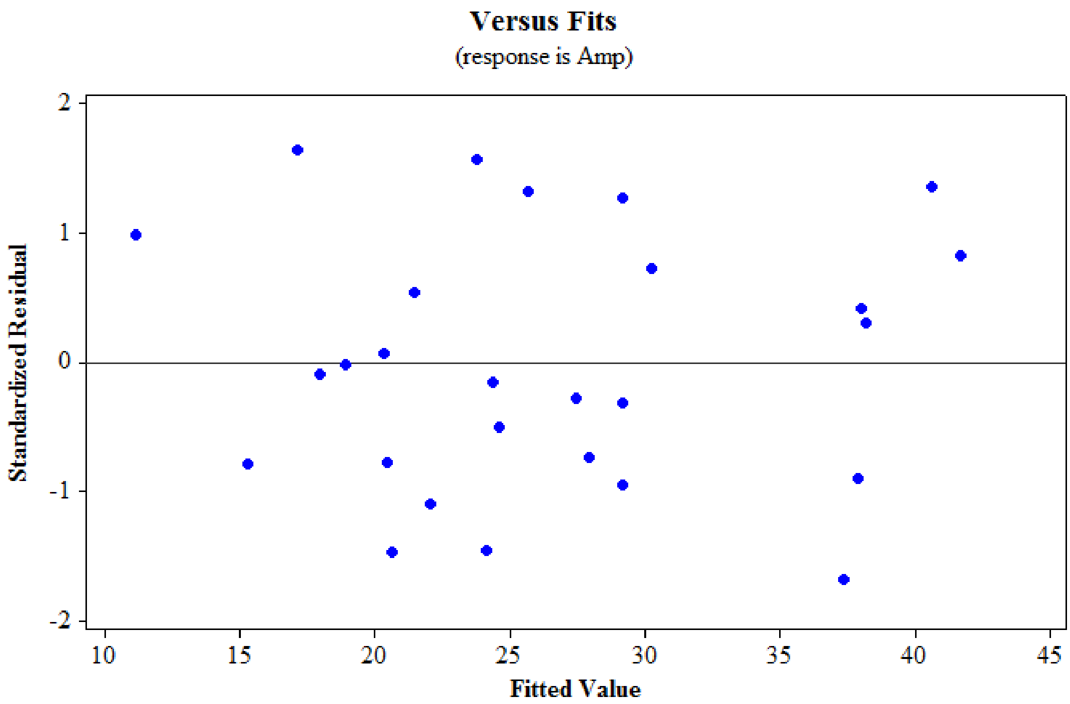


Figure 24 Residual versus predicted response for GFE as SBM for (Amp)

The ANOVA table for only Ra is presented here.

Table 18 ANOVA for second order model for Ra in milling for GFE as secondary bed material

Source	DF	Seq SS	Adj SS	Adj SS	F	P
Regression	13	9.70037	9.70037	0.74618	252.66	0
Linear	4	6.25643	5.9784	1.4946	506.08	0
Square	4	2.53116	2.53258	0.63315	214.39	0
Interaction	5	0.91277	0.91277	0.18255	61.81	0
Residual Error	13	0.03839	0.03839	0.00295		
Lack-of-Fit	11	0.03513	0.03513	0.00319	1.96	0.387
Pure Error	2	0.00327	0.00327	0.00163		
Total	26	9.73876				

It can be appreciated that the P-value is less than 0.05 which means that the model is significant at 95% confidence level. The ANOVA table for the second-order model proposed for Ra given in Eq. is as follows.

Table 19 ANOVA for model coefficients for Ra in milling for GFE as secondary bed material

Source	DF	Seq SS	Adj SS	Adj SS	F	P
f	1	0.43887	0.51948	0.51948	175.9	0
S	1	0.69447	0.95431	0.95431	323.13	0
d	1	0.8748	0.80765	0.80765	273.47	0
n	1	4.2483	3.72071	3.72071	1259.84	0
f*f	1	0.1447	0.31983	0.31983	108.3	0
S*S	1	2.19434	1.71474	1.71474	580.62	0
d*d	1	0.08128	0.0247	0.0247	8.36	0.013
n*n	1	0.11085	0.11128	0.11128	37.68	0
f*S	1	0.06382	0.06382	0.06382	21.61	0
f*n	1	0.3049	0.30587	0.30587	103.57	0
S*d	1	0.04154	0.04154	0.04154	14.07	0.002
S*n	1	0.04011	0.04011	0.04011	13.58	0.003
d*n	1	0.4624	0.4624	0.4624	156.57	0

Above table shows the ANOVA table for individual model coefficients where it can be noticed that all effects with a P-value less than 0.05 which means that they are significant at 95% confidence level. The main effect plot for secondary bed material GFE is as follows.

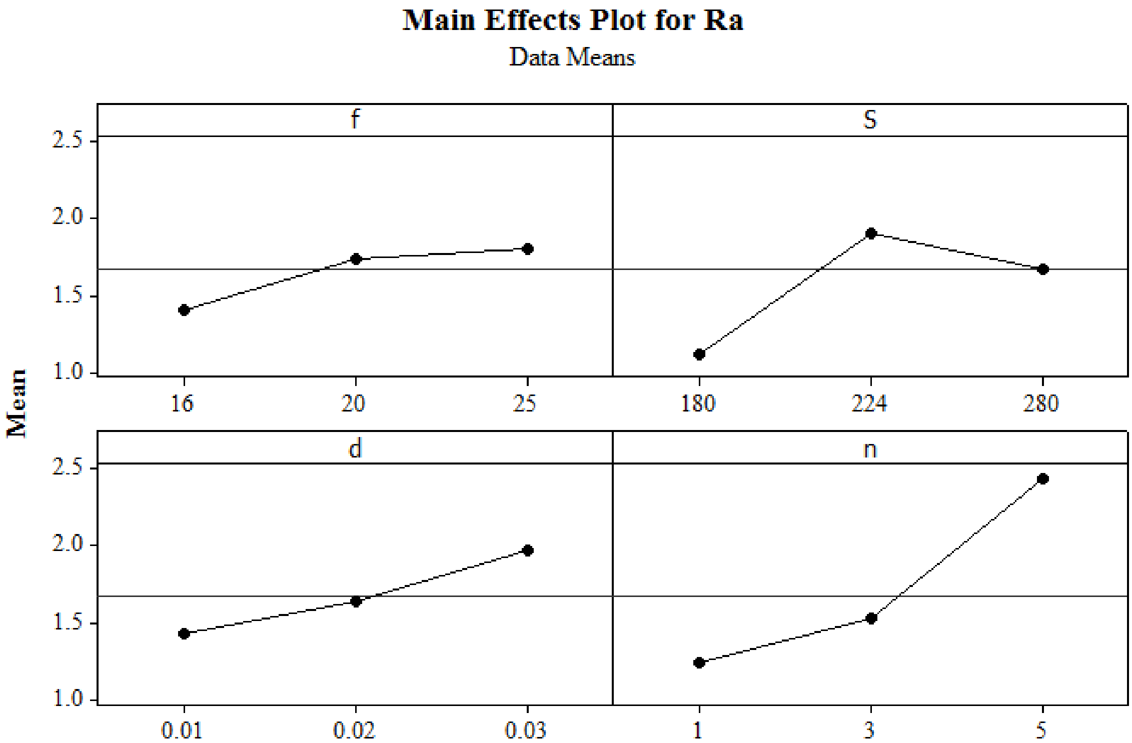


Figure 25 Main effect plot for GFE as SBM (for Ra)

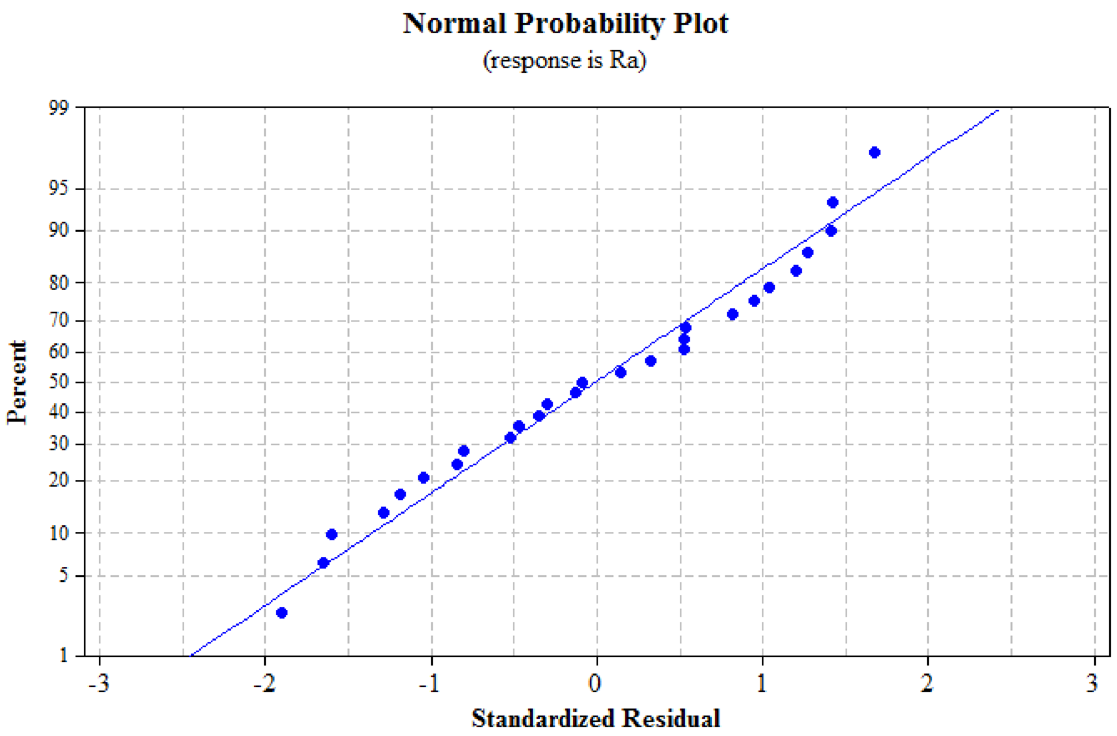


Figure 26 residual versus predicted response for GFE as SBM for (Ra)

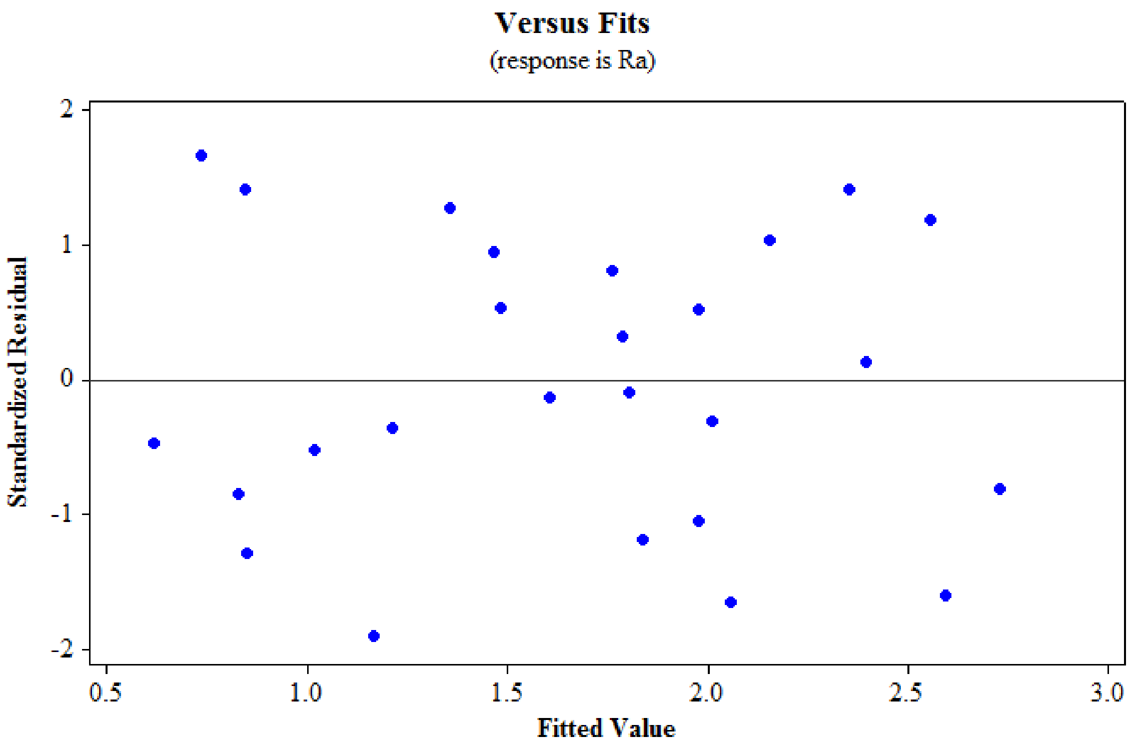


Figure 27 Residual versus predicted response for GFE as SBM for (Ra)

The normal probability plot of the residuals and the plot of residuals versus the predicted response for Ra are shown . A check on the probability plot of the shows that, the residuals fall on or near a straight line. This refers that the errors are distributed normally. Also residuals versus the predicted response plot reveal that there is no obvious pattern and unusual structure. This implies that the model proposed is adequate.

Chapter 6: Conclusion

6.1 Conclusions

1) In the present work, 3types of secondary bed materials are stacked together below the workpiece to form the sandwich and the main effect plot shows the variation of response parameter with respect to controllable parameter.

2) Finite Element Analysis based modal analysis helped in deducing the precautionary steps while doing the experiment.

3) RSM is utilized to develop model equation which shows the variation of response parameter with respect to controllable parameter.

4) The decrease of vibration amplitude has been observed with increase of number of layers interposed between table and work piece for PP and PVC but for GFE vibration increases of the experimental setting.

5) It can be concluded that for of the decided level setting PP and PVC are the useful secondary bed material than GFE.

Chapter 7: Scope for future work

7.1 Scope for future work

1. Damping ratio can be determined from experiment. This can lead to determination of Alpha and Beta damping coefficient by the formula named after Raleigh.

2. Experiments can further be conducted by taking five controllable parameter; feed, RPM, depth of cut, Numbers of layers of SBM and finally tightening torque to the know the influence on the responses that we have taken.

Chapter 7: References

7.1 References

[1] S. C. Sen and A. Bhattacharyya, Principles of Machine Tools, 2nd ed., 2009

[2] S. K. Basu and D. K. Pall Design of Machine Tool, 5th ed, 2008

[3] K. N. Koo, I. Lee “Vibration and damping analysis of composite laminates using deformable finite element”, AIAA J, Vol 31 (4), pp. 728-35, 1993.

[4] B. C. Routara & A. Bandyopadhyay and P. Sahoo, “Roughness modeling and ptimization in CNC end milling using response surface method: effect of workpiece material variation”, Int J Adv Manuf Technol, Vol 40, PP. 1166–1180, March 2008

[5] Lee, D.G., Chang, S.H. and Kim, H.S. “Damping improvement of machine tool columns with polymer matrix fiber composite materials”. Compos. Struct., 43,155–163, (1998).

[6] Suh, J.D., Lee, D.G. and Kegg, R. “Composite machine tool structures for high speed milling machines”. Annals CIRP, 51(1), 285–288, (2002).

[7] Rahman, M., Mansur, A. and Karim, B. “Non-conventional material for machine tool structures[J]”. JISM International Journal, Series C, 44(1), 1–11, (2001).

[8] Okubo, N., Yoshida, Y. and Hoshi, T. “Application of Modal Analysis to Machine Tool Structures”. Annals CIRP, 31(1), 243-246, (1982)

[9] J. Vantomme “A parametric study of material damping in fiber - reinforced plastics”, Department of Civil Engineering, Royal Military Academy , Avenue da le Renaissance 30, 1994.

[10] Haranath, S., Ganesan, N. and Rao, BVA. “Dynamic analysis of machine tool structures with applied damping treatment‖”. Int J Mach Tools Manuf, 27(1), 43-55, (1987),.

[11] Wakasawa, Y., Masatoshi, H. and Etsuo, M. “The damping capacity improvement of machine tool structures by balls packing‖”. Int J Mach Tools Manuf, 44(14), 1527-1536, (2004).

[12] B. J. Lazan, “Damping of Materials and Members in Structural Mechanics”, Pergamon Press London, 1968

[13] Bert, C.W., “Composite materials: A survey or the damping capacity of fiber reinforced composites in damping applications for vibration control”, AMD-Vol. 38. (1980).

[14] Nashif, A.D, Jones, D.I.G and Henderson, J.P. Vibration Damping, Wiley, New York, (1985).

[15] Gibson, R.F., Chaturvedi, S.K. and Sun, C.T., “Complex moduli of aligned discontinuous fiber-reinforced polymer composites”, J. Mater Sci., Vol. 17. pp. 3499-3509 (1982).

[16] Gibson, R.F., Chaturvedi, S.K. and Sun, C.T., “Internal damping of short-fiber reinforced polymer matrix composites”, Comput. Struct 20, pp. 391—401, (1985).

[17] Sun, C.T , Wu, J.K. and Gibson, R.F., “Prediction of material damping of laminated polymer matrix composits”. J. Mater. Sci. 22, pp. 1006-1012, (1987).

[18] Adams, R.D. and Bacon, D.G.C, “Effect of fiber orientation and laminate geometry on the dynamic properties of CFRP”, J Compos.Mater. 7, pp. 402-428, (1973).

[19] Lin D.X, Ni R.G and Adams R.D, “Prediction and measurement of the vibrational damping parameters of carbon and glass fibre-reinforced plastics plates”, J. Composite. Materials. 18, pp. 132 -152 (1984).

[20] Ni R.G and Adams R.D., “A rational method for obtaining the dynamic mechanical properties of lamina for predicting the stiffness and damping of laminated plates and beams”, Composites 15, pp. 193—199, (1984).

[21] Morison W.D, “The prediction of material damping of laminated composites”, Can. Aeronaut. Space J. 28, pp. 372-382, (1982).

[22] Kinra, V.K., Wren G.G., Rawal S.P. and Misra. M.S. "On the influence of ply-angle on damping and modulus of elasticity of a metal-matrix composite, Metals". Trans, 22A. pp. 641-651. (1991).

[23] Lin D.X, Ni R.G, Adams R.D. "Prediction and measurement of the vibrational damping parameters of carbon-glass fiber-reinforced plastic Plates". J Comp Mater; 18: 132-52.(1984).

[24] Ungar, E.E. and Kerwin, J.R., "Loss factors or viscoelastic systems in terms of energy concepts", J Acoust. Soc. Am., 34, No. 7, 954.958, (1962).

[25] Johnson C. D. and Kienholz D. A., "Finite element prediction of damping in structures with constrained Viscoelastic layers", AIAA J., 20, No. 9, 1284-1290,(1982).

[26] Koo K.N, Lee.I. "Vibration and damping analysis of composite laminates using deformable finite element". AIAA J; 31 (4): 728-35,(1993).

[27] Chandra, R., Singh S.P, and Gupta.K, "Damping studies in fiber-reinforced composites—a review". Composite Structs, 46(1), 41-51, (1999).

[28] T. Stolarski, Y. Nakasone, S. Yoshimoto, "Engineering analysis with ANSYS software", Elsevier Butterworth-Heinemann, 2006

[29] Ansys user manual.

[30] Minitab User Manual Release 13.2, Making data analysis easier. MINITAB Inc, State College, PA, USA, 2001

[31] R H. Myers and D. C. Montgomery, Responcse Surface Methodology, 2nd ed. 2002